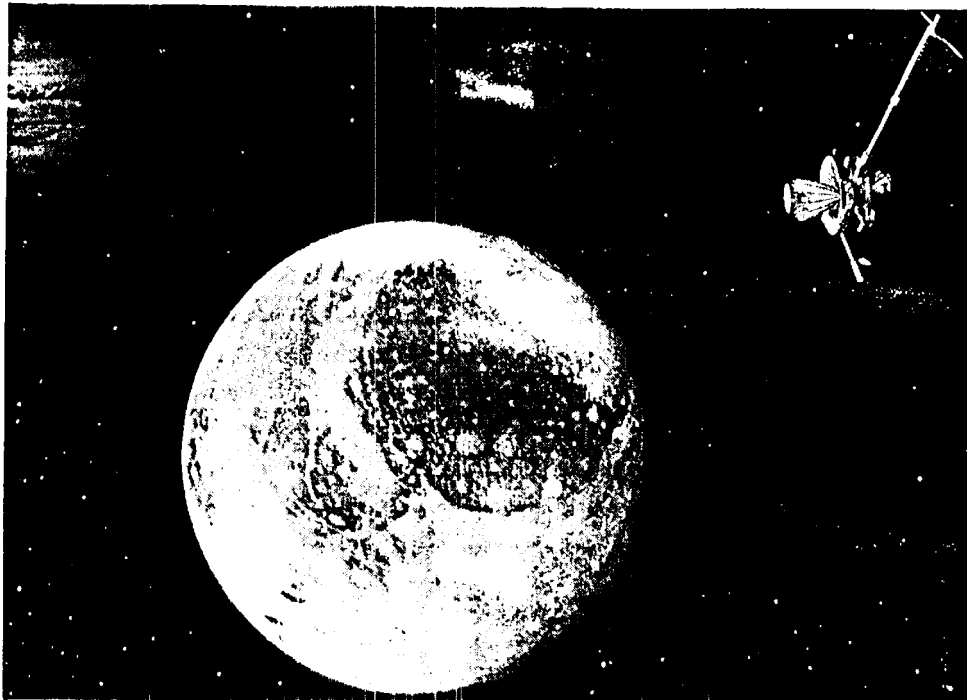


Galileo The Tour Guide



June 1996

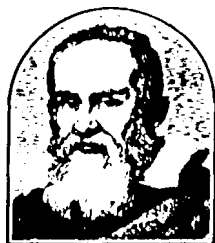


Jet Propulsion Laboratory
California Institute of Technology

JPL 13-13554

Fortune favors the bold. - Virgil

At this very moment, spacecraft Galileo is orbiting the planet Jupiter. We invite you to join us for an exciting 2-year mission, the first extensive visit to an outer planet and its satellites.



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SECTION 1



ABOUT THIS GUIDE

Project Galileo has prepared this guide to help you share with us a unique experience. The Galileo spacecraft tour is the first time an orbiter has explored an outer planet and its satellite system.

In this guide, we offer a look back and a look ahead. The basics are here—our reasons for going, the journey so far, the spacecraft structure for both orbiter and probe, the instruments aboard each, our arrival at Jupiter with a quick look at the science results, and the satellite tour itself.

En route to Jupiter the skill, energy, and dedication of many contributed to discoveries and the gathering of scientific information despite difficulties. Arrival Day made it all worthwhile when the orbiter and probe performed flawlessly. The planning begun years ago and fine-tuned along the way had become a reality.

And more mysteries to be solved lie ahead as even now Galileo is collecting data while approaching Ganymede for the first encounter of the tour. We've listed some ways you can keep up with the news. It's available on the Internet and in hard copy.

World Wide Web:

The Galileo home page: <http://www.jpl.nasa.gov/galileo>

JPL *Info* Computer Bulletin Board Service: <http://www.jpl.nasa.gov>

Online From Jupiter: <http://quest.arc.nasa.gov/jupiter.html>

NASA JPL Learning Link: <http://learn.jpl.nasa.gov>

NASA SpaceLink: <http://spacelink.msfc.nasa.gov>

Gopher:

NASA SpaceLink: spacelink.msfc.nasa.gov

Anonymous FTP:

JPL *Info* Computer Bulletin Board Service: jplinfo.jpl.nasa.gov (137.78.104.2). Log on as **anonymous**, then send your city and state (city and country for foreign users) as the password (commas and spaces are ok, up to a total of 15 characters).

NASA SpaceLink: spacelink.msfc.nasa.gov (192.149.89.61)

Modem:

JPL *info* Computer Bulletin Board Service: Dial (818) 354-1333.
Set parameters to no parity, 8 data bits, 1 stop bit. This line supports speeds up to 9600 baud.

NASA SpaceLink: Dial (205) 895-0028. Set parameters as follows:
terminal emulation at VT-100 and data format at 8-N-1.

Hard Copy:

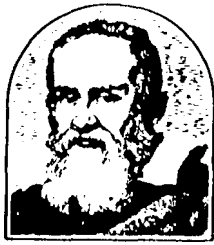
The Project Galileo newsletter, *The Galileo Messenger*
(also available on the World Wide Web);
to receive a copy, call the editor at (818) 354.5593.

Contact Galileo Educational Outreach (818) 393-0593,
Public Information Office at (818) 354-5011, or
Teaching Resource Office at (818) 354-5011
to receive additional materials.

NASA Television (NTV)

NTV is broadcast on Spacenet 2, transponder 5, channel 9, C-band,
located at 69 degrees West longitude. The frequency is 3880 MHz.
Polarization is horizontal and audio is monaural at 6.8 MHz.

SECTION 2



THE JOURNEY TO JUPITER

VEEGA— The Solution

Every cloud has a silver lining. Consider the journey of Galileo from Earth to Jupiter. When the Challenger exploded in January 1986, preparations were underway to launch Galileo in May. This launch would have used a shuttle to carry the spacecraft to low-Earth orbit. Galileo would then have been boosted to Jupiter using the powerful Centaur rocket as an upper stage.

The Galileo project was hit by a double whammy. First, the shuttle fleet was grounded while problems were identified and fixed. Second, the Centaur was forbidden to be canied on a space shuttle.

Mission designers worked to find another way to Jupiter. Several ideas were suggested. One idea was to split the flight system into two pieces and launch each separately. All the proposed schemes were either too costly or not able to accomplish all the mission's scientific objectives.

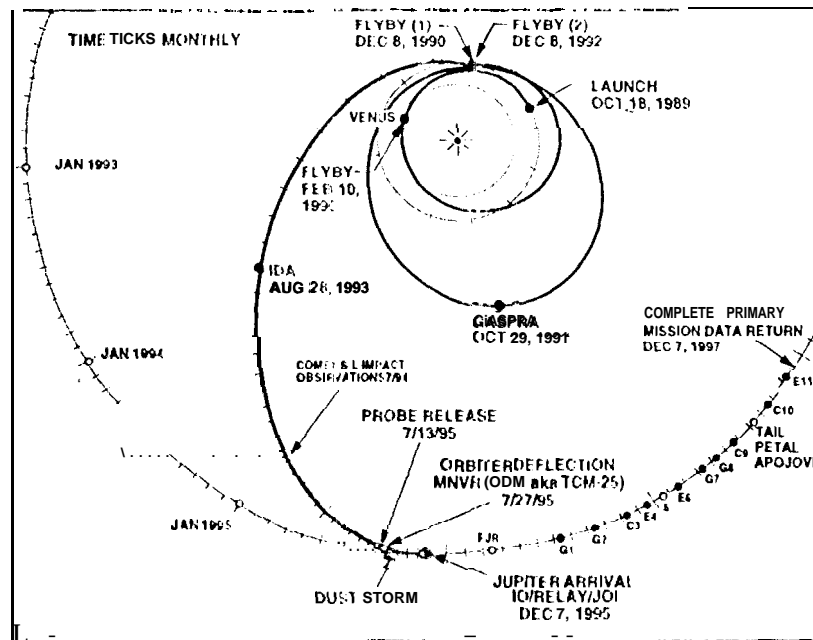
Finally, trajectory experts discovered that if they launched the spacecraft toward the planet Venus they would be able to get to Jupiter using a series of gravity assists. The spacecraft would flyby Venus and then twice by the Earth itself. These three gravity assists would make up for chemical energy that was lost with the banned Centaur rocket. The trajectory was named "VEEGA" for "Venus-Earth Earth Gravity Assist."

A gravity assist occurs when a spacecraft flies past a massive body at just the right place. The spacecraft receives a boost in energy (and a change in direction) by the gravitational action of the body.

One of the big drawbacks of the VEEGA trajectory was that going near Venus would bring the Galileo spacecraft closer to the Sun than it had been designed to fly. (Venus is only two-thirds of Earth's distance from the Sun.) So, spacecraft engineers had to change the thermal protection of Galileo to prevent damage as it swung toward the Sun. Other drawbacks included having to add another low-gain antenna, a lot of aging analysis caused by the extended time here and in space, and a concern about avoiding Earth.

With the VEEGA trajectory, scientists realized that there was indeed a silver lining. The complex path to Jupiter would carry the Galileo spacecraft by several interesting objects. The detour was not just an annoying delay. Fascinating opportunities lay ahead.

The VEEGA Trajectory



Liftoff!

Galileo was launched aboard the Space Shuttle Atlantis on October 18, 1989. In place of the Centaur, the Inertial Upper Stage (IUS) was used to boost the spacecraft on its journey. Along the way to Jupiter there were encounters with Venus (February 10, 1990), Earth-1 (December 8, 1990), asteroid 951 Gaspra (October 29, 1991), Earth-2 (December 8, 1992), and asteroid 243 Ida (August 28, 1993). In addition to their science value, these encounters were used to calibrate and characterize the spacecraft's instruments in support of its future activities at Jupiter.

On February 10, 1990, the Galileo spacecraft flew to within 16,000 kilometers of Venus. Scientific observations, including 81 images of the planet, were performed from closest approach – 1 day to + 7 days during the encounter period. The pictures of cloud-covered Venus revealed new information on the structure and dynamics of the thick atmosphere.

Venus Flyby, An Infrared Image of the Clouds

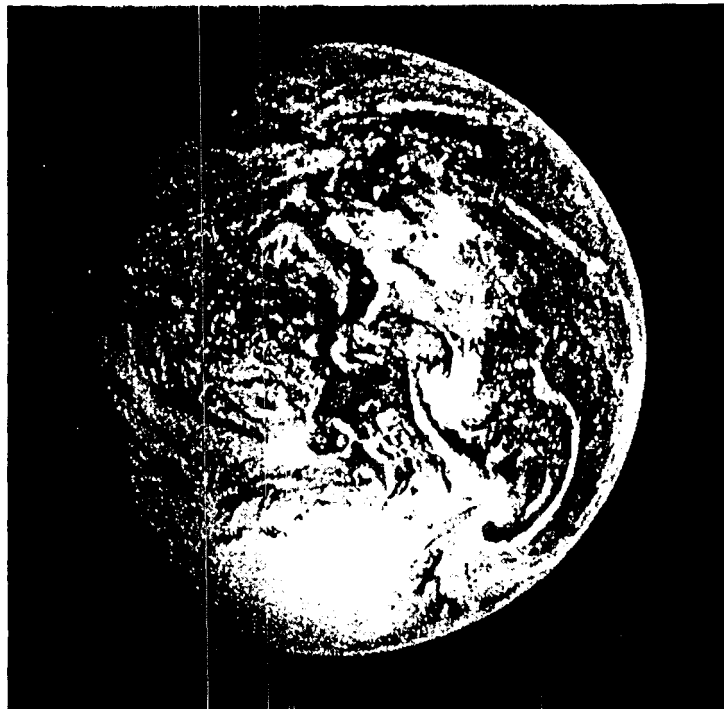


Galileo looped back to Earth later that year. The spacecraft passed above the surface at an altitude of 960 kilometers. Galileo took more than 1000 pictures of Earth to create an Earth-rotation movie. This movie displayed weather patterns from Galileo's unique perspective.

**How Aliens
Would See Us**

At a press conference after the Earth-1 encounter, the Project Scientist, Dr. Torrence Johnson, provided a unique ovm-view of the flyby. He imagined Galileo was an alien spacecraft from somewhere near the star Arcturus. What would the aliens have learned about planet Earth? They would know that Earth's oceans were not very deep since the planet's density was more than 5 times that of water. A magnetic field would have been detected. This field would allow them to deduce the presence of the planet's fluid, conducting core. The chemistry of the atmosphere, with its low amount of carbon dioxide and high amount of oxygen, might indicate life. Radio signals, most likely not of natural origin, would have been detected. This further supported the possibility of life. "I here were probably volcanoes, but no active volcanoes were spotted. Plate tectonics were not detected. Johnson concluded his talk by saying that the Arcturan Academy of Sciences would certainly ask their government to fund another mission to Earth, preferably an orbiter.

Earth Flyby



The High-Gain Antenna

In April 1991, the Galileo flight team prepared to open the spacecraft's 4.8-meter mesh high-gain antenna. The antenna had been stowed like a closed umbrella since launch. People are always nervous about doing a major mechanical operation in space. You can't go out there with your tool box if it doesn't work. This time their worst fears came true. The antenna failed to open.

For many months, the problem was studied and various fixes were attempted---heating, the antenna using sunlight, cooling it by turning it toward the cold darkness of deep space, and trying to force it open with its motors. The device remained stuck,

Analysis of the available engineering measurements showed that the antenna had only partially opened. It was of little or no use as a communications device. Reluctantly, the project began to consider how to carry out its mission using only the low-gain antenna to transmit data to the ground,

The recovery strategy had two main thrusts. First, the sensitivity of the Deep Space Network (DSN) was increased substantially. (The DSN is a network of three deep space communications facilities located around the Earth at about 120 degrees apart, allowing constant observation of a spacecraft as the Earth rotates.) Second, methods of compressing data onboard the spacecraft before they were sent to the ground were developed. That way fewer "bits" could do the work of more. So effective were the plans of spacecraft engineers and mission planners that it has been estimated 70 percent of Galileo's original scientific objectives will be met.

Cruising the Asteroid Belt

Asteroid 951 Gaspra was the next target after Earth-1. The closest approach to Gaspra, on October 29, 1991, was at 1600 kilometers. Imaging of the asteroid started at one Gaspra "day" (7 hours and 3 minutes) before closest approach. Images were taken as close as 5000 kilometers. Approximately 60 percent of the surface was photographed. Objects as small as about 50 meters could be seen in some images. The images were stored on the spacecraft's tape recorder for later transmission over the low-gain antenna. This first space encounter with an asteroid showed it to be an irregular object (19 by 12 by 11 kilometers) covered with craters.

The December 1992 flyby of Earth went smoothly. Closest approach was at an altitude of only 305 kilometers. (The space shuttle, the space transportation system or STS, typically orbits the Earth at an altitude of

immediately upon the heels of the Ida data return, it became apparent that the Galileo spacecraft would have a direct view of an extremely rare event. It would witness the impact of a comet with Jupiter. No Earth-based telescope would be similarly favored.

The Comet Spectacle—S-1.9

Gene and Carolyn Shoemaker and David Levy discovered a fragmented comet on March 24, 1993. Since the comet was the ninth discovered by this team, it was labeled "Shoemaker-Levy 9" (S-1.9). The discovery was made with the 0.5-meter Schmidt telescope at the Palomar Observatory in California.

Originally a periodic comet in orbit about the Sun, the comet was captured by Jupiter. It may have broken into pieces in July 1992 when it passed about 100,000 kilometers from the giant planet. By cosmic standards, this is a very close passage, but when astronomers examined the future path of the cometary fragments, they were astounded to find that in July 1994 the comet would actually slam into Jupiter.

Galileo was approximately 240 million kilometers from Jupiter at the time of the impacts. All told, 23 fragments splashed into the atmosphere between July 16 and July 22 while Galileo performed many scientific observations from its unique perspective.

*S-1.9 Arrives at
Jupiter*



Cruise Highlights

Venus	<ul style="list-style-type: none">• Confirmation of lightning (PWS)• Images of mid-cloud level (NIMS)• Images of surface (NIMS)
Earth, Moon	<ul style="list-style-type: none">• Unique measurements of the distant regions of the magnetotail (MAG, PLS)• Discovery of intelligent life (PWS)• Earth rotation movie (SSI)• Movie of Moon passing in front of Earth (SSI)• Images of Antarctica (SSI)• Visual and infrared images of the Andes mountains (NIMS, SSI)• Visual and infrared images of the lunar farside and the polar regions (NIMS, SSI)
Asteroids (Gaspera, Ida)	<ul style="list-style-type: none">• First and second close encounter with an asteroid (all instruments except HIC)• Discovery of first confirmed asteroid moon, Dactyl (NIMS, SSI)• Unexpected solar wind/asteroid interaction - magnetic signature? (MAG)
Comet Collision with Jupiter (Shoemaker- Levy 9)	<ul style="list-style-type: none">• Only direct observations of impacts (SSI, PPR, NIMS, UVS)• Only direct characterization of the size and temperature of the impact fireball (NIMS, PPR, UVS)• Detection of the "splash-back" of the material ejected from the impacts (NIMS)
Interplanetary Cruise	<ul style="list-style-type: none">• Discovery of the most intense dust storm ever recorded (IDS)• Mapping of hydrogen and helium distribution in the solar system (EUV, UVS)• Characterization of large solar flare (HIC)
Engineering	<ul style="list-style-type: none">• Demonstration of deep-space optical communication using laws (SSI)• Complete rework and reloading of primary computer software (AACS, CDS)

Note: Acronym Definitions:

AACS = Attitude and Articulation Control subsystem	NIMS = Near-Infrared Imaging Spectrometer
CDS = Command and Data Subsystem	PLS = Plasma Subsystem
IDS = Dust Detector Subsystem	PPR = Photopolarimeter Radiometer
EUV = Extreme Ultraviolet (Spectrometer)	PWS = Plasma Wave Subsystem
HIC = Heavy Ion Counter	SSI = Solid-State imaging
MAG = Magnetometer	UVS = Ultraviolet Spectrometer

Probe Release and ODM

The final major mission event in getting ready for Jupiter arrival occurred in July 1995. On July 13, the atmospheric probe was cut loose from the orbiter. The probe was pushed gently away, continuing, on a trajectory that guided it into Jupiter's atmosphere on December 7. The probe could not communicate with the orbiter during the cruise to Jupiter.

The orbiter had to be deflected from its course so it wouldn't follow the probe into the atmosphere of Jupiter. The orbiter deflection maneuver (ODM) occurred on July 21. It was the first major use of the 400-newton main engine of the spacecraft. After 6 years in space, the propulsion system functioned well. (Except for a 2-second wake-up burn 5 days earlier, this engine actually had not been fired since 1984.)

At ODM the engine burned 308.1 seconds. Valuable data on engine characteristics were gained. These data were used to plan the burn sequence to insert the orbiter into a trajectory about Jupiter. After a burn lasting 49 minutes, the orbiter would begin its 7-year tour of the gas giant and its complement of satellites, rings, and magnetosphere.

The Tape Recorder Challenge

The Jupiter approach phase officially began on October 9, 1995. On October 11, the orbiter recorded a global image of Jupiter with the probe entry site in view. When the tape recorder was commanded to rewind so that the picture could be transmitted to Earth, Project personnel received an unexpected jolt. Data from the spacecraft showed that the tape recorder had failed to stop rewinding.

After commands were sent in real time to stop the recorder, engineers quickly began an extensive analysis of the problem. Was the tape broken? Was it slipping? Had the tape recorder actually stopped but sent a faulty reading?

On October 20, the tape recorder was tested and a few seconds of data were played back. The tape recorder was still operational! However, a preliminary study indicated that the tape recorder could be unreliable under some of the planned Jupiter approach operating conditions.

On October 24, the spacecraft executed commands for the tape recorder to wind an extra 25 times around a section of the tape. This section was possibly weakened where the recorder was stuck in rewind mode for about 15 hours. Indications were that the tape had not moved during this entire time. The drive mechanisms had been slipping and possibly rubbing against the tape. Spacecraft engineers are uncertain about the condition of this area of tape so it is now "off-limits" for future recording. The extra tape wound over it secures that area of tape, eliminating any stresses that

could tear the tape at this potential weak spot. Unfortunately, the approach image of Jupiter that Galileo took on October 11 is stored on the off-limits portion of the tape and will not be played back.

Engineers continued to analyze the tape recorder's condition so that they could fully understand its capabilities and potential weaknesses. They hoped to find ways to operate the recorder with little loss to the orbital mission objectives. Consequently, the decision was made to use the tape recorder, but sparingly, on approach to Jupiter. All imaging and other high-rate data (including the pictures of Europa and IO) were eliminated from the arrival sequence. Only the low-rate data opportunities were recorded: the probe data and the unique fields and particles data in the IO torus.

Looking back, the cruise phase of Galileo was very valuable. The spacecraft was characterized, assuring us of the performance we could expect from it. The instruments were calibrated. We added to our knowledge of Venus, the Earth, and the Moon. We rewrote the chapter on asteroids. We had the best perspective on the cosmic show provided by Shoemaker-Levy 9.

The wonders of Arrival Day--to be remembered always--are told in Section 6, Arrival at Jupiter.



THE PLANET JUPITER

For thousands of years, people have watched a bright wandering light in their sky. Only one other wanderer (Venus) was brighter, but it never appeared high in the night sky. This "wandering star" or planet was named after the ruler and most powerful of the Roman gods of mythology-- Jupiter.

Jupiter is the largest planet in the solar system. It is about two and a half times more massive than the other eight planets combined. If it were hollow, more than 1300 Earths could fit inside. However, Jupiter's density is only a little more than that of water. It is a gas planet, not a rocky one like Earth.

Through a telescope, Jupiter appears as a yellowish disk, crossed with orange-red bands. Since the mid- 1600s, astronomers have noted spots moving across Jupiter's face as the planet rotates. Some of these spots and other cloud features have survived for years at a time, much longer than clouds and storm systems do on Earth. The longest lived of these spots is the "Great Red Spot." This gigantic red oval (about three times the size of Earth) was first reported in 1664.

Astronomers have used these moving spots to roughly measure the planet's rotation period. A Jupiter "day" is just under ten hours. Jupiter has the highest rotation period of any planet, causing the slightly squashed appearance of the disk. The equatorial radius is 4300 kilometers larger than the polar radius.

Early Explorations

Five spacecraft from Earth have already made the journey to Jupiter. Pioneers 10 and 11, launched in 1972 and 1973, respectively, were the first spacecraft to explore space beyond the orbit of Mars, cross the asteroid belt, and provide close looks at the giant planet. The Pioneer spacecraft were "spinners." They rotated constantly like giant tops. This design was very stable and required less complicated guidance than a non-spinning craft.

The instruments could collect data from many different directions while the spacecraft was spinning. Instruments measuring energetic particles and magnetic fields perform well on a spinning spacecraft. Other types of instruments, such as cameras, do not do as well. Imagine trying to take a picture while you were riding a merry-go-round. The Pioneers carried 11 instruments. Some were for sensing small meteoric particles and charged particles. Some were for measuring Jupiter's magnetic field and radiation. One instrument, the imaging photopolarimeter, measured the brightness of a narrow strip of the planet. It took a measurement during each spin of the spacecraft. An image of Jupiter was assembled from these strips.

Voyagers 1 and 2 were launched on their tours of the outer planets in 1977. The Voyager missions were designed to study the planetary systems in greater detail than the Pioneers had done. The Voyager spacecraft were more sophisticated and more automated than the Pioneers. Also, these spacecraft were not spinners but were "three-axis stabilized." Voyager was able to maintain a fixed orientation], or attitude, in space. The spacecraft provided accurate and steady pointing for its instruments. However, the instruments could not continuously sample different directions. Voyager carried ten instruments, including television-like cameras, spectrometers, particle detectors, and a magnetometer.

The latest visitor to Jupiter, Ulysses, was launched in 1990 and arrived in early 1992. Ulysses' prime mission was to study the poles of the Sun. The spacecraft used Jupiter's gravity to swing upward out of the ecliptic plane so it could examine the polar regions of the Sun. The spinner spacecraft carried nine instruments (no camera-like devices) designed to study the Sun, the solar wind, and interstellar space. These instruments supplied data about Jupiter's magnetosphere.

How We Compare

Characteristic	Earth	Jupiter
Equatorial Diameter (km)	12,756	142,984
Mean Relative Density (g/cm ³)	5.52	1.33
Mean Distance From Sun (km)	149,600,000	778,400,000
Orbital Rotation	365.25 days	12 Earth years
Rotational Period	23 h, 56 min	9 h, 55 min
Atmosphere	78% nitrogen 21 % oxygen	81% hydrogen 18% helium

The Atmosphere

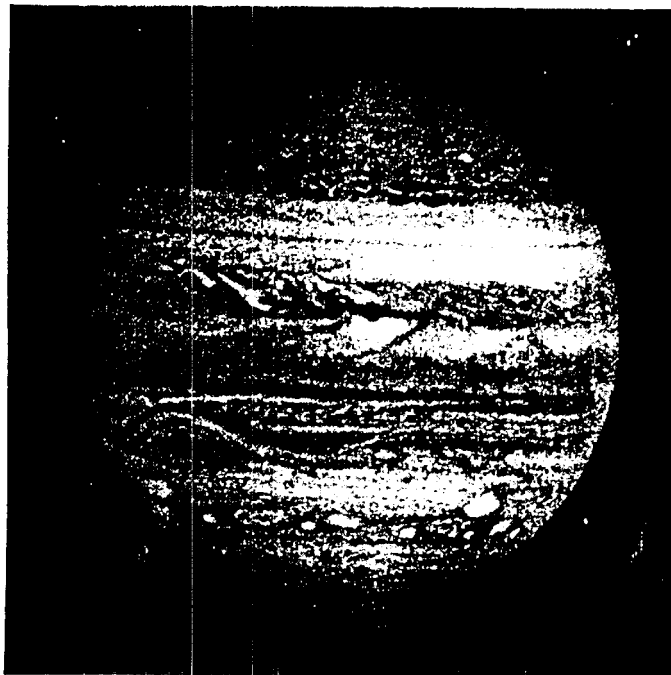
Based on the data obtained from the Pioneer and Voyager missions, Jupiter's atmosphere consists of about 81 percent hydrogen and 18 percent helium. If Jupiter had been between fifty and a hundred times more massive, it might have evolved into a star rather than a planet. Our solar system could have been a binary star system. Besides hydrogen and helium, small amounts of methane, ammonia, phosphorus, water vapor, and various hydrocarbons were found in Jupiter's atmosphere.

Jupiter's atmosphere displays alternating patterns of dark belts and light zones. The locations and sizes of the belts and zones change gradually with

time. Within these belts and zones are clouds and storm systems that have raged for years. One of these giant storms, called the "Great Red Spot," has lasted over 300 years. This spot rotates once counter-clockwise every 6 days. Since it is in the southern hemisphere of the planet, this rotational direction indicates it is a high-pressure zone (unlike Earth's cyclones, which are low-pressure zones). The reddish color is a puzzle to scientists, but several chemicals, including phosphorus, have been proposed. In fact, the colors and mechanisms driving the appearance of the entire atmosphere are not well understood. These mysteries cannot be solved by taking pictures. Direct measurements from within the atmosphere are necessary- measurements like those made by the Galileo probe.

Jupiter is swept by about a dozen prevailing winds, reaching 150 meters per second (335 miles per hour) at the equator. On Earth, winds are driven by the large difference in temperature, more than 40 degrees Celsius (about 100 degrees Fahrenheit), between the poles and the equator. But, Jupiter's pole and equator share the same temperature, -130 degrees Celsius (about -200 degrees Fahrenheit), at least near the cloud tops. This is another mystery being addressed by Galileo (see Probe Science Results).

*Jupiter's
Great Red Spot*



The Interior

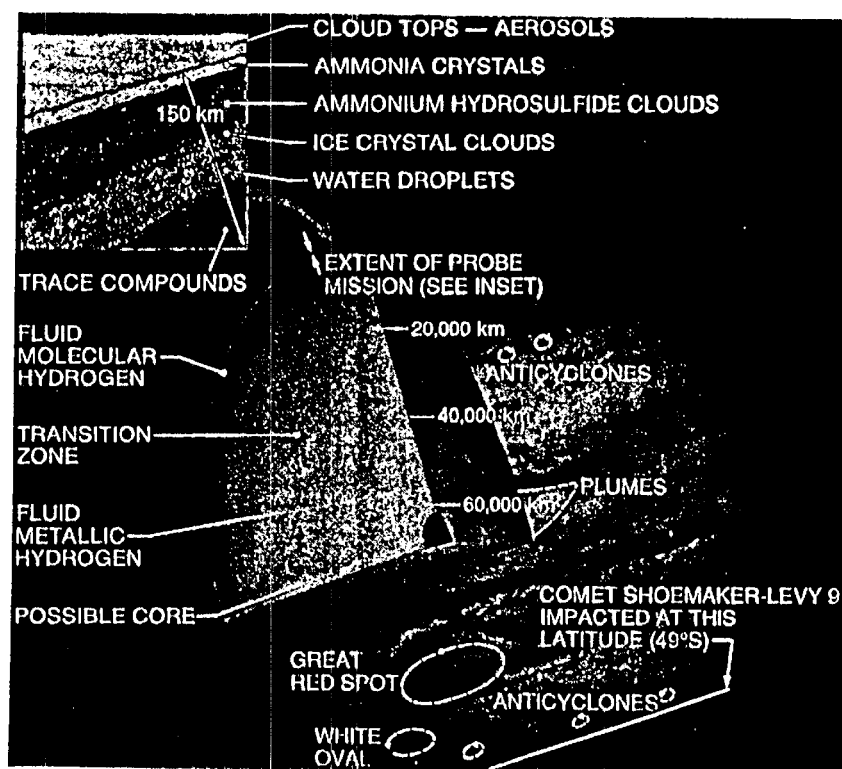
Jupiter's core is estimated to be about one-and-a-half times Earth's diameter, yet ten to thirty times more massive. The core's temperature is estimated to be 30,000 degrees Celsius (about 55,000 degrees Fahrenheit). This high temperature is the result of a pressure of as much as a hundred million atmospheres. (One atmosphere is equal to the air pressure at sea level on Earth.)

Surrounding this core is a 40,000-kilometer (25,000-mile) deep sea of liquid metallic hydrogen. Unknown on Earth, liquid metallic hydrogen forms under the extreme pressures that exist on Jupiter. At this depth, the pressure is more than three million atmospheres. Hydrogen molecules are so tightly packed that they break up and become electrically conductive. Scientists believe it is this electrically conductive liquid that causes Jupiter's intense magnetic field.

Next there is a 21,000-kilometer (13,000-mile) thick layer of hydrogen and helium. This layer gradually changes from liquid to gas as the pressure falls into the range of tens of atmospheres.

Finally, a 150-kilometer (100-mile) thick cloud cover, the atmosphere, tops the planet.

*Jupiter—Front
Core to Cloud Top*



The Ring

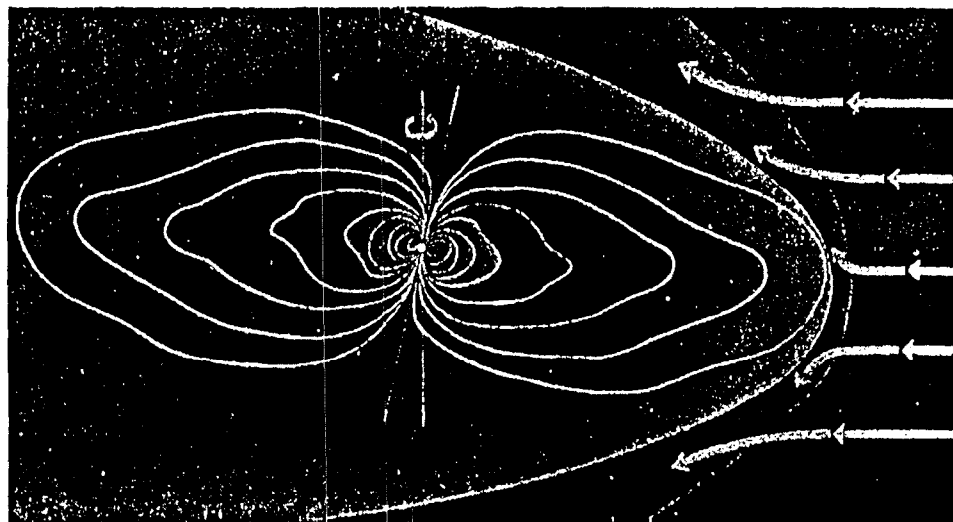
One of the surprising discoveries made by Voyager was the detection of an extremely faint ring around Jupiter. The scientists who designed Voyager's observations decided to take pictures of the area where they thought a ring might be. The lighting, was just right for them to capture the ring made up mostly of dark, dust-sized particles. The ring, consisting of three bands, extends from the upper atmosphere out to about 53,000 kilometers (33,000 miles) above the cloud tops. The brightest band is at the outer edge and is 800 kilometers (500 miles) wide.

The Magnetosphere

One of the by-products of Jupiter's ocean of liquid metallic hydrogen is a magnetic field stronger than that of any other planet. Jupiter's magnetic field has the opposite sense of Earth's. A compass would point south rather than north. The region of space dominated by a planet's magnetic field is called a "magnetosphere." Jupiter's magnetosphere is molded by the solar wind (the stream of charged particles "blown" out from the Sun) into a teardrop shape--its point directed away from the Sun. If Jupiter's magnetosphere were visible from Earth, it would be several times larger than the full Moon in the night sky.

The magnetosphere is dominated by the planet's environment, its magnetic field, and a swarm of energetic particles and gases. The low-energy ions, protons, and electrons are called "plasma." The boundary between the magnetosphere and the solar wind is the "magnetopause." A bowshock is formed in the solar wind upstream from the magnetopause. In the direction away from the Sun, the magnetosphere is drawn out in a long "magnetotail" by the drag of the solar wind.

*Jovian
Magnetosphere
and Solar Wind
Interaction*

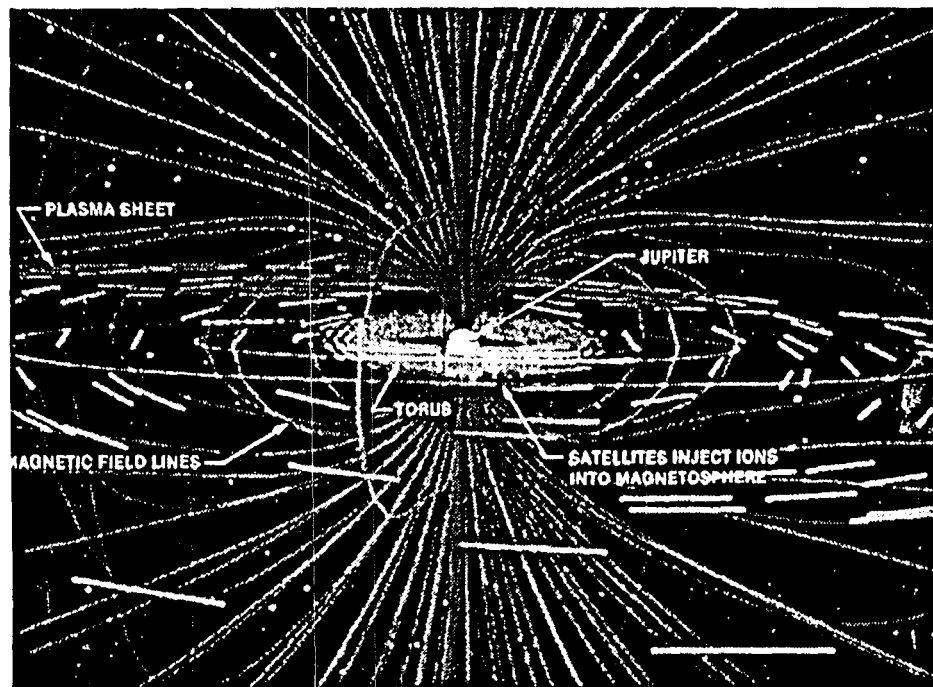


Distributed throughout the magnetosphere is a low-energy plasma, largely concentrated within a few planetary radii of the equatorial plane. The plasma forms a sheet through which concentrated electric currents flow (see the figure below).

The Pioneers and Voyagers observed a giant doughnut-shaped collection of charged particles surrounding Jupiter at about the distance of the orbit of Io. This is known as "the 10 plasma torus." It results from material escaping from Io's atmosphere or surface and then being caught up in Jupiter's magnetic field.

At Jupiter, the plasma within the magnetosphere tends to rotate along with its rotating magnetic field. If it rotates at the same speed, it is referred to as "rigid corotation." Processes within the magnetosphere cause the plasma to rotate at less than rigid corotation speeds in some regions.


*The Plasma Sheet,
Io's Torus, and the
Magnetic Field Lines*



The Satellites

Thirteen of Jupiter's 16 known moons were discovered from Earth. The other three were first seen by Voyager. The four largest moons—Io, Europa, Ganymede, and Callisto ---were observed in 1610 by Galileo Galilei of Italy. He used a newly invented device called a "telescope." These four moons are often referred to collectively as "the Galilean satellites." What do we already know of these moons? They range in size from slightly smaller than our Moon to slightly larger than Mercury. The top figure shows the order of the satellites' proximities to Jupiter (moon sizes are not to scale), and the bottom figure shows the comparison of their sizes to one another.

Distances From Jupiter

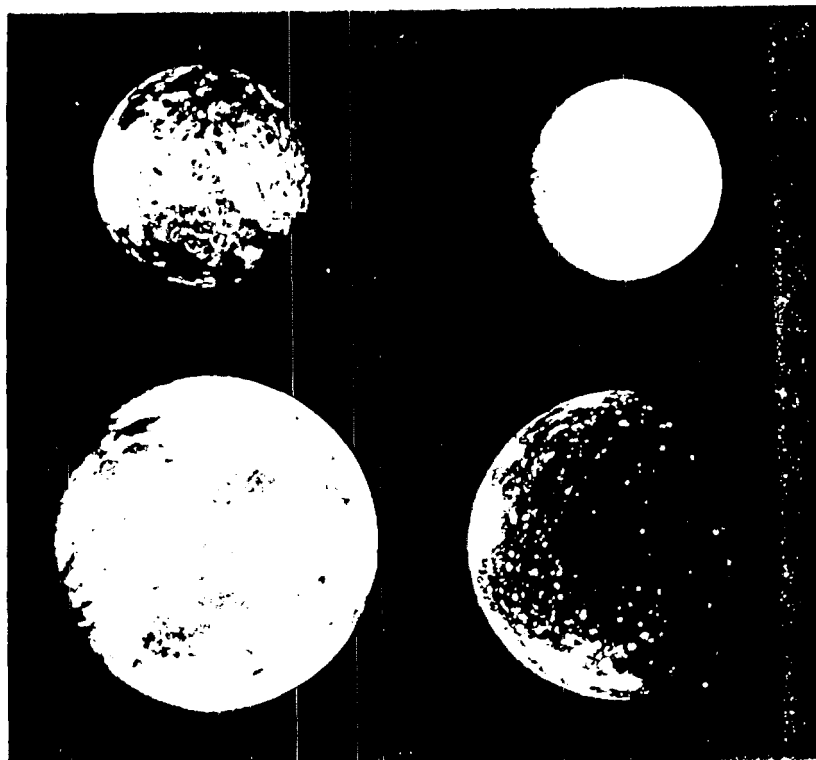

Jupiter	Io	Europa	Ganymede	Callisto
778.3 x 10 ⁶ (from Sun)	421,600	670,900	1,070,000	1,880,000
71,398 (equatorial)	1,81535	1,5649 ± 10	2,631 ± 10	2,400 ± 10
1.9 x 10 ²⁷	8.92 x 10 ²²	4.87 x 10 ²²	1.490 x 10 ²³	1.075 x 10 ²³
1.314	3.55	3.04	1.93	1.83
				- Mean distance (km) -
				- Radius (km) -
				- Mass (kg) -
				- Bulk density (g/cm ³) -

Callisto will be placed on Pic

Io

Relative Size

Ganymede

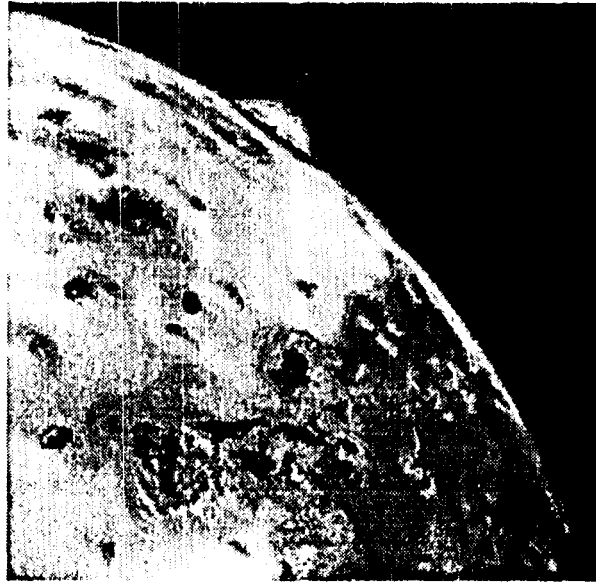


Europa

Callisto

10, the Galilean satellite nearest Jupiter, has been described as looking like” a giant pizza (due to its bright mcdish-orange and white markings) or the closest place to hell in the solar system. Volcanoes spew plumes of gas and solid particles hundreds of kilometers above the surface. A collection of these particles, trapped by the magnetic force from Jupiter, orbit the planet in the shape of a huge doughnut known as the “Io Plasma Torus.” Flows of sulfur lava radiate from the volcanoes. Approximately one third of the surface is covered with bright white sulfuric snow. It may be that the intense volcanic activity on 10 results from frequent great tides caused by the gravitational influence of Jupiter. Galileo found that 10 has a large, dense iron core, taking up half its diameter (see Arrival at Jupiter section).

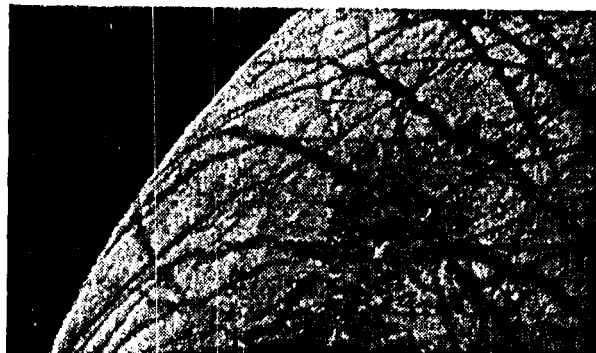
Volcanoes Galore!



Europa

If Io is a pizza, then Europa, the next satellite out from Jupiter, is a cracked hard-boiled egg. It has a bright white surface, crisscrossed with dark fissures. It has neither mountains nor valleys, craters nor volcanoes. Recent observations from Earth indicate the moon may have a thin atmosphere of oxygen and sodium. Some scientists think that a giant ocean may lie beneath a layer of ice that has cracked and refrozen at temperatures of about -146 degrees Celsius or -230 degrees Fahrenheit. If so, it would be the only place we know of in our solar system besides Earth with a significant supply of liquid water. Still--too cold for a swim!

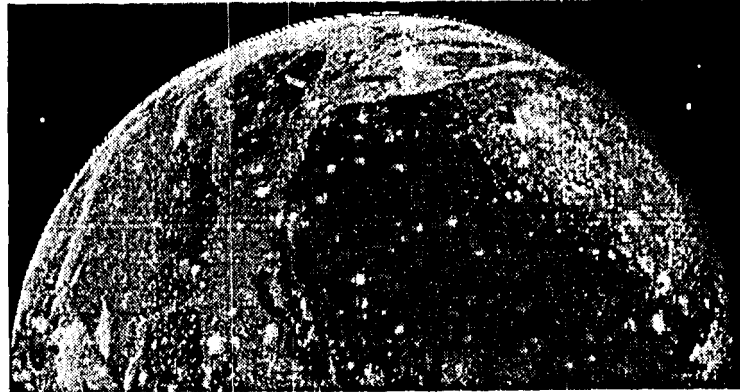
Cracks in the Ice?



Ganymede

The third Galilean satellite, Ganymede, is the largest moon in the solar system. It has a variety of geological formations, including craters and basins, grooves, and rough mountainous areas. About half the surface is covered with water ice and half with dark rock. These heavily cratered dark regions are thought to be ancient. The newer, lighter regions give evidence of tectonic activity that may have broken up the icy crust. A thin layer of ozone has been detected surrounding Ganymede.

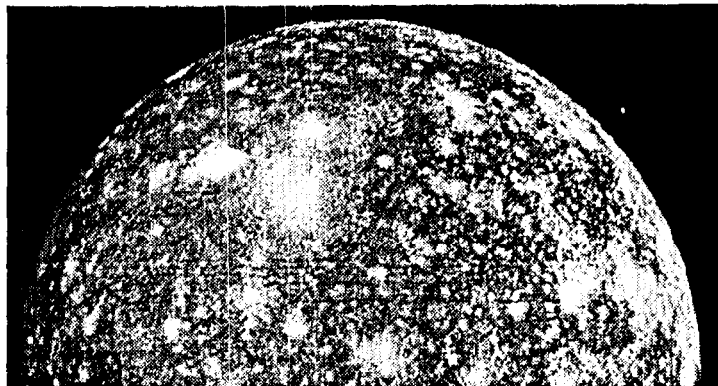
*Bigger Than
Mercury*



Callisto

The last and least active of the Galilean satellites is Callisto. Like Ganymede, it seems to have a rocky core surrounded by an ocean of ice. The surface is covered completely with meteoric impact craters; no "plains" show. Although the exact rate of impact crater formation is not known, scientists estimate that it would require several billion years to accumulate the number of craters found on Callisto. Therefore, the moon must have been inactive at least that long, a fine record of the past.

*Cluttered With
Craters*



The Minor Satellites

All the other satellites are comparatively mine: objects, up to 170 kilometers (100 miles) across. Eight are in inclined orbits far from the planet, and four are close to the planet, inside Io's orbit. In ascending order of mean distance from Jupiter, the 16 moons are Metis, Androstea, Amalthea, Thebe, Io, Europa, Ganymede, Callisto, Leda, Himalia, Lysithea, Elara, Ananke, Carme, Pasiphae, and Sinope. Online From Jupiter (see World Wide Web in the first section, About This Guide) sponsored a contest to create a mnemonic to help you remember this long list. One winner gave us "Meteors and asteroids travel in every galaxy continuously" for the first eight moons. You may want to devise your own sentence from the initial letters of the last eight satellites!

What We Hope To Learn?

Studying Jupiter may help us to understand how the solar system, and our own planet, formed and evolved. The flyby missions of the Pioneers, Voyagers, and Ulysses gave us quick glimpses of this exciting world. Now it is time to settle in and take long-term, detailed measurements of the system.

The Galileo mission was composed of two elements to do just this. A probe descended into the atmosphere to sample it directly (see two sections, The Galileo Probe and Probe Science Results). An orbiter will spend almost 2 years studying the planet, its satellites, and the vast magnetosphere up close. (Galileo will orbit Jupiter in the altitude range of 650,000 to 800,000 kilometers. Closest approach for earlier missions was 1,200,000 kilometers during the Voyager flyby.)

The composition of Jupiter's atmosphere may tell us about the original star stuff from which all the planets formed. There are many unanswered questions about Jupiter that Galileo will try to answer. What is the current state of Jupiter's atmosphere? What are its clouds made of? How do temperature and pressure change with depth? What is the strength of its winds? What are the forces behind its weather patterns? What causes the lightning that Voyager observed flashing on the night side of the planet? The Probe mission has already provided some clues. Learning more about Jupiter's atmosphere will advance our understanding of the nature of all planetary atmospheres, including our own.

By studying Jupiter's satellites we hope to determine the effects of initial conditions, size, energy sources, meteorite bombardment, and tectonic processes on the way planets evolve. Among the key questions about the satellites are the following: How did Io's volcanoes evolve and what is their chemical composition? How thick is Europa's ice crust and what lies beneath it? What causes the appearance of the terrain on Ganymede? How do the craters on Callisto compare with craters on rocky planets?

What are the interiors of the satellites like? What are their atmospheres (if any) like? Do they have magnetic fields? .

observations of the magnetosphere will help us to understand the complex interactions between magnetic forces and matter throughout the universe. There are many questions about the magnetosphere. What is the inter-action between the satellites and the magnetosphere? What are the origins of the magnetotail wind?

We should always remember that even though we have many ideas about what we anticipate Galileo will accomplish, the most exciting results are often unexpected.

***Galileo Science
Objectives***

Atmosphere

- Determine the chemical composition
- Determine the structure to a depth of at least 1(1 bars
- Determine the nature of the cloud particles and location and structure of cloud layers
- Determine the difference between the amount of energy being received from the Sun and the amount of energy coming from inside Jupiter
- Investigate the wind patterns
- Investigate the upper atmosphere and ionosphere

Satellites

- Characterize the appearance, geology, and physical state of the surfaces
- Investigate the surface mineralogy and surface distribution of minerals
- Determine the gravitational and magnetic fields and dynamic properties
- Study the atmospheres, ionospheres, and extended gas clouds
- Study the interactions of the satellites with the magnetosphere

Magnetosphere

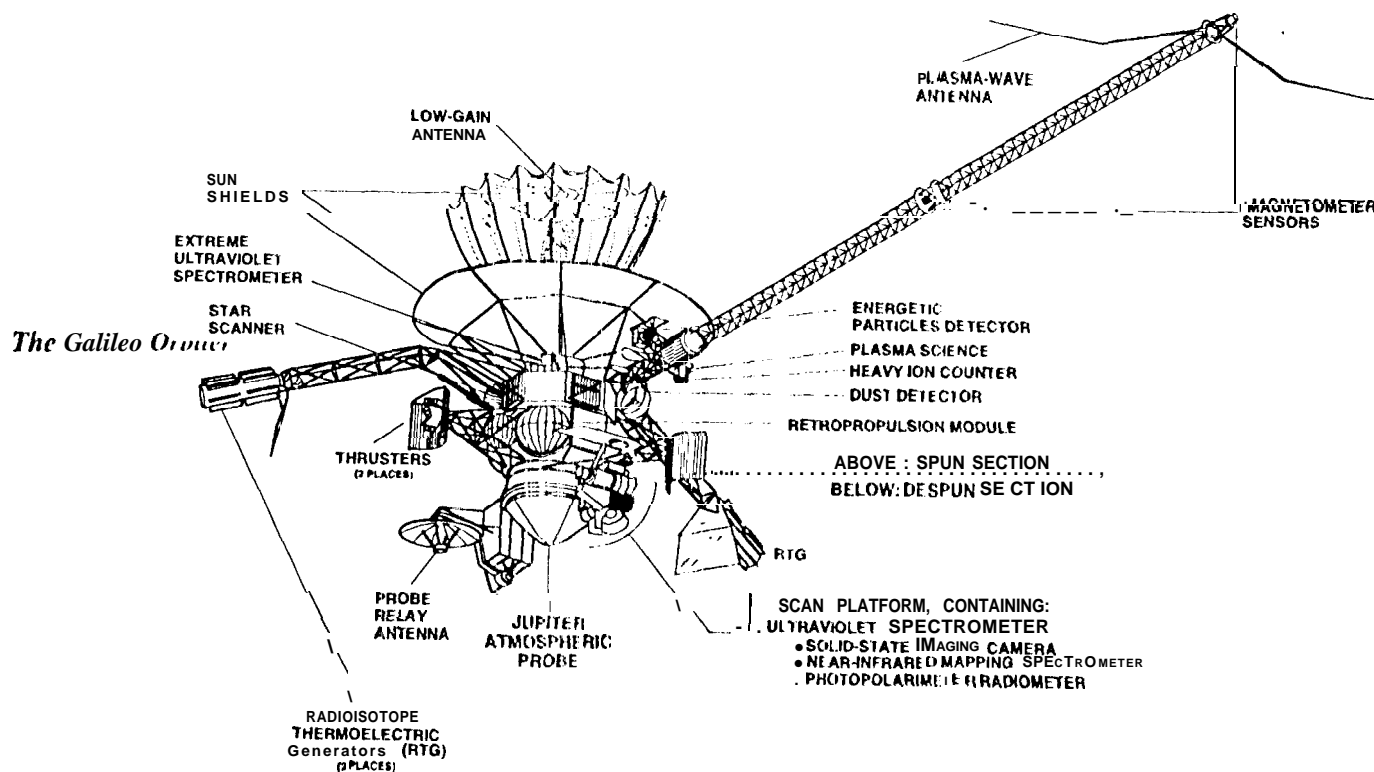
- Characterize the energy spectra, composition, and distribution of energetic particles throughout the magnetosphere
 - Characterize the direction and strength of magnetic fields throughout the magnetosphere
 - Characterize the plasma energy spectra, composition, and angular distribution throughout the magnetosphere
-



THE GALILEO ORBITER

The Galileo orbiter, built at JPL, combines features of spinner spacecraft (the Pioneers and Ulysses) and three-axis stabilized spacecraft (the Voyagers). The orbiter is an innovative "dual-spin" design. Part of the orbiter (containing the antennas and some instrument booms) rotates while another part (containing an instrument platform) remains fixed in inertial space. This means that the orbiter is a good platform for fields and particles experiments; they perform best when rapidly gathering data from many different directions. The orbiter is also a good platform for remote sensing experiments that require very accurate and steady pointing.

At launch, the orbiter weighed 2223 kilograms, including 118 kilograms of science instruments and 925 kilograms of usable rocket propellant. The overall length from the top of the low-gain antenna to the bottom of the probe measured 47 meters; the magnetometer boom extends 11 meters from the center of the spacecraft.



Spacecraft Subsystems

The Galileo orbiter is composed of the following major engineering subsystems and science instruments.

Power Subsystem

Galileo uses two radioisotope thermoelectric generators (RTGs) to supply electrical power to run the spacecraft's devices. The radioactive decay of plutonium produces heat that is converted to electricity. The RTGs produced about 570 watts at launch. The power output decreases at the rate of 0.6 watts per month and was 493 watts when Galileo arrived at Jupiter.

Telecommunications

The problem with the high-gain antenna has made it necessary to communicate with Earth—data down and commands up—through a low-gain antenna. Instead of 134 kilobits per second through the 4.8-meter high-gain antenna, up to 160 bits per second will be sent to Earth from Jupiter.

Command and Data Subsystem

The Command and Data Subsystem (CDS) (really the “brain” of Galileo) has several functions. First, it must carry out instructions from the ground to operate the spacecraft and gather science data. Second, some portions of the CDS memory can serve as a storage place for science data. Third, the CDS must package the data for transmission to Earth. Finally, the CDS must be alert for and respond to any problem with any of the spacecraft subsystems.

Commands sent from Earth can be in the form of real-time (do this now) commands or as a sequence, a set of instructions for operating the spacecraft. Sequences are carefully constructed (with input from many scientists and engineers) and thoroughly tested before being radioed to the spacecraft. On Galileo, a sequence may control spacecraft operations for a period of hours to several months, depending upon how busy the period is.

In March of 1995, the capability to write probe data to the CDS memory was added via an in-flight loading of new software. Doing so allowed the CDS to serve as a limited backup to the tape recorder for storage of the probe data. As of spring 1996, data compression methods will have been added to the CDS software. These methods will allow retention of the most interesting and scientifically valuable information, while minimizing or eliminating less valuable data (such as the dark background of space) before transmission. The final crucial function of the CDS is fault-protection activation. Fault protection algorithms make the spacecraft semiautonomous and able to act quickly to protect itself. There are occasions in the lives of most spacecraft when emergencies must be handled, and there is no time to wait for answers from the flight team on Earth.

**Data Memory
Subsystem**

Data are either transmitted to Earth as they are gathered (called “real-time data”), or they are stored aboard for future playback. One place data can be stored is Galileo’s Data Memory Subsystem (DMS), a four-track tape recorder that holds 900 megabits of data.

**Attitude and
Articulation
Control
Subsystem**

The Attitude and Articulation Control Subsystem (AACS) is responsible for attitude determination (determining the orientation of the spacecraft in inertial space), attitude propagation (keeping track of the spacecraft orientation between attitude determinations), and attitude control (changing the orientation, spin rate, or wobble of the spacecraft). Software in the AA(X) computer carries out the calculations necessary to do these functions. In the spring of 1996, the software will have been updated to include the ability to compress imaging and plasma wave data down to as little as 1/80th of their original volume.

**Propulsion
Subsystem**

The Propulsion Subsystem consists of the 400-newton main engine and twelve 10-newton thrusters together with propellant, storage and pressurizing tanks, and associated plumbing. The fuel for the system is monomethylhydrazine, which is burned using nitrogen tetroxide. The Propulsion Subsystem was developed and built by Daimler Benz Aerospace AG (DASA) (formerly Messerschmitt-Bölkow-Blohm) and provided by Germany, a long-term partner in Project Galileo.

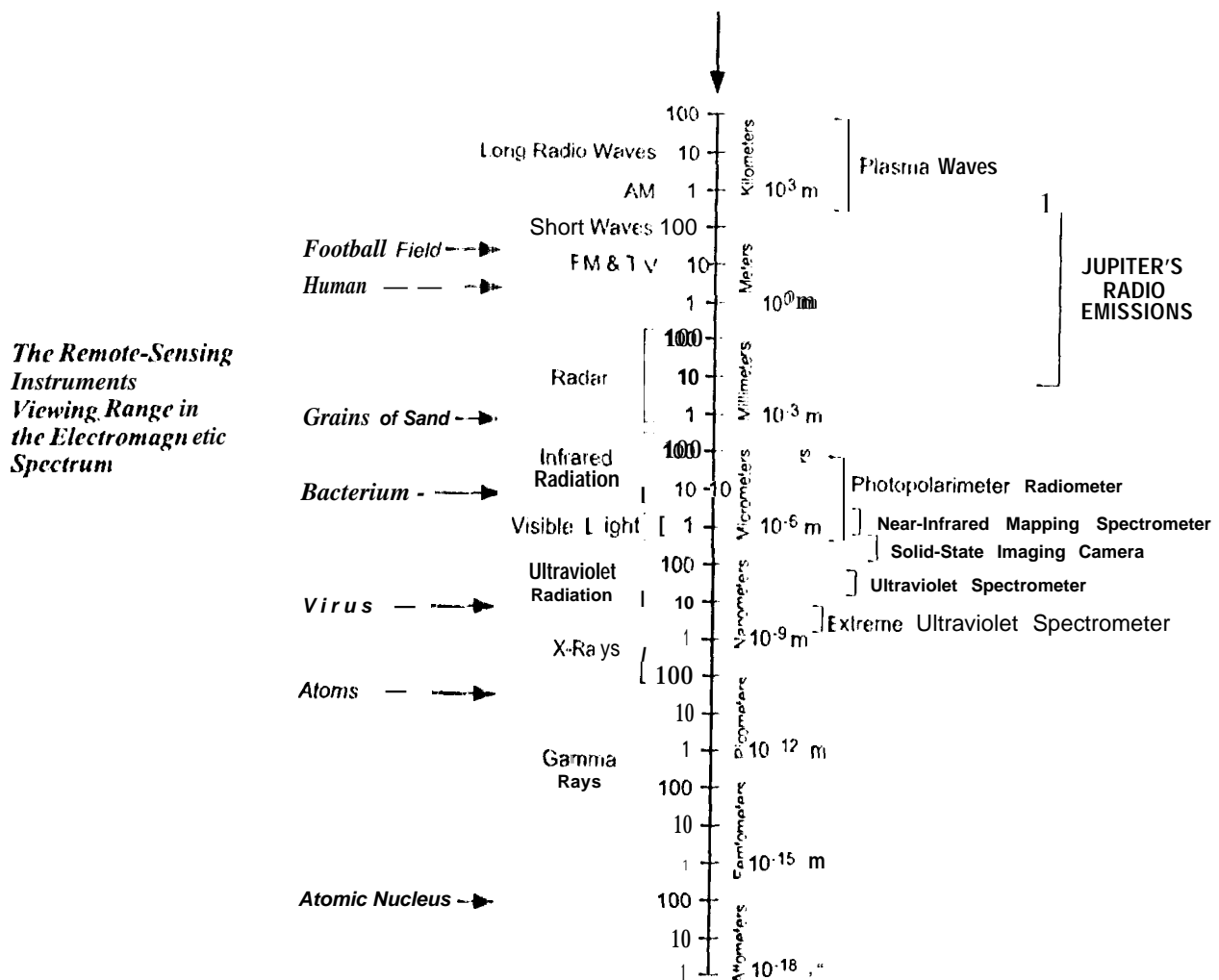
The newton (N) is a unit of force used to measure, among other things, the thrust level of rocket engines. A thrust of 10 N would support a weight of about 1 kilogram (or 2.2 pounds) at the Earth’s surface.

**Scientific
Investigations**

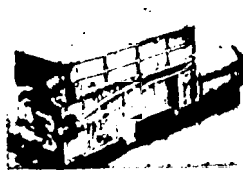
There are 12 scientific experiments aboard the Galileo orbiter. The despun section is home to four remote-sensing instruments. These are mounted on a movable scan platform with their optical axes aligned so that they view a nearly common area. The spun section contains six instruments that investigate particles and magnetic fields. The remaining two investigations use the radio system of the orbiter.

Renlote-Sensing Instruments

For Jupiter and its moons, the remote sensing instruments will be acquiring data that may reveal the history of the Jovian system and its present composition and processes. The figure shows the wavelength ranges of the electromagnetic spectrum that these instruments will monitor during both encounters and cruise periods.



Solid-State Imaging Camera



The scientific objectives of the solid-state imaging (SS1) camera investigations have a wide scope: a study of satellite sciences, a study of the Jovian atmosphere, characterization of Jovian and satellite auroral phenomena, and an assessment of the rings of Jupiter. For the Galilean satellites Io, Europa, Ganymede, and Callisto, the imaging investigators hope to map a large portion of each surface to a resolution of 1 kilometer or better. In a few areas, features smaller than 100 meters will be distinguished. In addition, variations in color and albedo (reflectivity) will be mapped at a scale of about 2 kilometers. Scientists will look for changes on the surfaces over time. It is also planned to measure the shape and the location of the spin axis of each Galilean satellite.

The other smaller satellites will be studied throughout the orbital tour. Studies will also be made of Jupiter's rings. Small, new satellites maybe found in or near the rings.

The SS1 will be used to determine structure, motions, and radiative properties of the atmosphere of Jupiter. It will measure wind profiles by tracking how fast clouds move at various altitudes. Radiative properties of the atmosphere, which are important for understanding energy management, will be determined by measuring the scattering of light from specific features at various wavelengths and at various angles of illumination. Observations of auroral phenomena will be correlated with fields and particles measurements done with other instruments.

The SS1 is an 800- by 800-pixel solid-state camera consisting of an array of silicon sensors called a "charge-coupled device" (CCD). The optical portion of the camera is built as a Cassegrain (reflecting) telescope. Light is collected by the primary mirror and directed to a smaller secondary mirror that channels it through a hole in the center of the primary mirror and onto the CCD. The CCD sensor is shielded from radiation, a particular problem within the radiation-harsh Jovian magnetosphere. The shielding is accomplished by means of a 1-centimeter-thick layer of tantalum that surrounds the CCD except, of course, where the light enters the system.

An eight-position filter wheel is used to obtain images of scenes through different filters. The images may then be combined electronically on Earth to produce color images.

The spectral response of the SS1 ranges from about 0.4 to 1.1 micrometers. (A micrometer is one millionth of a meter.) Visible light has a wavelength covering the band of 0.4 to 0.7 micrometers.

The SS1 weighs 29.7 kilograms and consumes, on average, 15 watts of power.

*Near-Infrared
Mapping
Spectrometer*



The near-infrared mapping spectrometer (NIMS) is a pioneering instrument for remote-sensing devices for planetary spacecraft. It combines spectroscopy and imaging in one instrument. The coldest part of the spacecraft is the NIMS radiator at 55 kelvin!

NIMS has two major objectives. The first objective is to look at the surfaces of the satellites of Jupiter to see what they're made of. The second objective is to study the atmosphere of Jupiter to determine such things as the characteristics of the Jovian cloud layers, the variations over time and space of the constituents of the atmosphere, and the temperature versus altitude profile.

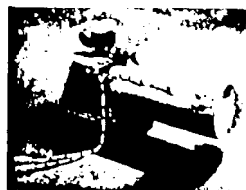
For the satellites, the geological structures will be mapped to determine their mineral distributions. Resolutions of 25 kilometers per NIMS pixel or better are planned for the Galilean satellites Europa, Ganymede, and Callisto. NIMS will make distant observations of Jupiter's volcanic moon Io, at resolutions of 120 to 600 km, to determine the moon's surface composition and to measure temperatures of the hot spots. NIMS will monitor Io's volcanic activity in every Galileo orbit. In addition, spectral analyses will be done for some of the smaller satellites and the planet's ring.

Since NIMS measures infrared radiation from the atmosphere of Jupiter, it will contribute to compositional studies, the nature of clouds, motions, and energy balances. NIMS will be able to monitor ammonia, water vapor, phosphine, methane, and germane and to look for previously undetected molecules. Phosphine, which is formed in the deep interior (more than 1000 kilometers deep below the clouds at temperatures near 1000 kelvin) and is rapidly destroyed at observable altitudes, is a tracer of huge upwellings of gas from deep inside the planet. NIMS will map the abundance of phosphine over a wide range of latitudes and longitudes. The goal is to understand the deep-seated circulation patterns that power the "near-surface" meteorology (planet-girdling cloudy zones, drier belts, and localized cyclonic storm systems such as the Great Red Spot).

The NIMS instrument is sensitive from 0.7 to 5.2 micrometers, overlapping the wavelength range of SS1. The telescope associated with NIMS is all reflective (uses mirrors and no lenses) with an aperture of 229 millimeters. The spectrometer of NIMS uses a grating to disperse the light collected by the telescope. This method is often used by instrument makers rather than use of the familiar prism. The dispersed spectrum of light is focused on detectors of indium antimonide and silicon.

The NIMS weighs 18 kilograms and uses 12 watts of power on average.

*Photopolarimeter/
Radiometer*



The photopolarimeter/radiometer (PPR) will be used to measure the intensity and polarization of sunlight, in the visible portion of the spectrum, that is reflected from -scattered from- the Jovian satellites and Jupiter. The PPR is in many respects three instruments combined into one: a polarimeter, a photometer, and a radiometer.

The polarimeter detects three spectral bands. Polarization is an important property of light (a fact known to the wearers of some types of sunglasses) and can reveal information about the nature of the object from which the light comes.

The photometer uses seven narrow spectral bands in the visible and near-infrared wavelengths. The bands in which to make these measurements have been carefully selected. For example, locations are covered where methane and ammonia strongly absorb light.

The PPR has seven radiometry bands. One of these uses no filters and observes all the radiation, both solar and thermal. Another band lets only solar radiation through. The difference between the solar-plus-thermal and the solar-only channels gives the total thermal radiation emitted. The PPR will also measure in five broadband channels that span the spectral range from 17 to 110 micrometers. The radiometer provides data on the temperatures of the Jovian satellites and Jupiter's atmosphere.

The design of the instrument is based on that of an instrument flown on the Pioneer Venus spacecraft. A 10-centimeter-aperture reflecting telescope collects light, directs it to a series of filters, and, from there, measurements are performed by the detectors of the PPR.

The PPR weighs 5.0 kilograms and consumes about 5 watts of power.

*(Ultraviolet
Spectrometer/
Extreme
Ultraviolet
Spectrometer*

TBS

The Galileo ultraviolet spectrometer investigation consists of two instruments: the ultraviolet spectrometer (UVS) and the extreme ultraviolet spectrometer (EUV). The UVS works on the short wavelength side of the visible band, operating from 113 to 432 nanometers. The EUV is a modified flight spare of the Voyager ultraviolet spectrometer and covers the range of 54 to 128 nanometers.

The UVS/EUV will study properties of Jupiter's atmosphere and aurora, the surfaces and atmospheres of the Galilean satellites, and the doughnut-shaped cloud of ionized plasma in Io's orbit. Absorption and reflectance spectra from the atmospheres of Jupiter and its satellites, characteristic of certain atoms and molecules, will be combined with the study of airglow emissions (emissions that occur because of sunlight and electron impacts).

The reflective properties of satellite surfaces in the ultraviolet allow scientists to determine the composition and physical state of the materials that comprise the surface. One can look for ice and frost or deduce the sizes of grains.

Volcanic eruptions on Io are believed to be the source of a large doughnut-shaped cloud of electrons and ionized sulfur and oxygen ions that encircles Jupiter along the orbital path of Io. (The mathematical name for a doughnut shape is "torus" so this cloud is called the "Io torus.")

Temperatures of the sulfur and oxygen ions in this plasma torus can be more than 10 times the temperatures at the surface of the Sun. These ultraviolet observations will help provide a picture of Io's evolution and its relationship with Jupiter's magnetic field.

The Cassegrain telescope of the UVS has a 250-millimeter aperture and collects light from the observation target. Both the UVS and EUV instruments use a ruled grating to disperse this light for spectral analysis. This light then passes through an exit slit into photomultiplier tubes that produce pulses or "sprays" of electrons. These electron pulses are counted, and these count numbers are the data that are sent to Earth.

The UVS is mounted on the scan platform and can be pointed to an object in inertial space. The EUV is mounted on the spun section of the spacecraft. As Galileo spins, the EUV observes a narrow ribbon of space perpendicular to the spin axis.

The two instruments combined weigh about 9.7 kilograms and use 5.9 watts of power.

Fields and
Particles
Instruments

As a set, the fields and particles instruments are designed to study numerous phenomena within the magnetosphere of Jupiter.

Plasma (as in the Io torus) is a very important ingredient of the magnetosphere. The sources of the plasma are being investigated. Which particles come from the ionosphere of Jupiter, which from the solar wind, and which from the satellites?

The plasma interactions with the satellites and particularly the parameters of the Io torus are of interest. The Jovian radiation belts and other structures of the magnetosphere will also be under scrutiny. Also, it is possible that a plasma wind will be found to flow out from Jupiter at the magnetotail.

Magnetometer



A basic set of measurements for fields and particle science is the determination of the strength and direction of the magnetic field within the magnetosphere.

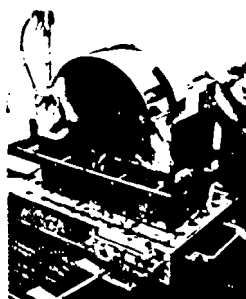
The magnetometer (MAG) uses two sets of three sensors. The three sensors allow the three orthogonal components of the magnetic field section to be measured. One set is located at the end of the magnetometer boom and, in this position, is about 11 meters from the spin axis of the spacecraft. The second set, designed to detect stronger fields, is 6.7 meters from the spin axis. The boom is used to remove the MAG from the immediate vicinity of the spacecraft to minimize magnetic effects from the spacecraft. However, not all these effects can be eliminated by distancing the instrument. The rotation of the spacecraft is used to separate natural magnetic fields from engineering-induced fields.

Another source of potential error in measurement comes from bending and twisting of the long magnetometer boom. To account for these motions, a calibration coil is mounted rigidly on the spacecraft and puts out a reference magnetic field during calibrations.

The strength of a magnetic field is measured in units of "tesla." The magnetic field at the surface of the Earth has a strength of about 50,000 nT. (The letter "n" stands for the prefix "nano," which indicates one thousand millionths of a tesla, or, in scientific notation, 10^{-9} tesla.) At Jupiter, the outboard (11-meter) set of sensors can measure magnetic field strengths in the range from ± 32 to ± 512 nT while the inboard (6.7-meter) set is active in the range from ± 512 to $\pm 316,384$ nT. The calibration coil provides a reference field at the outbound magnetometer of ± 3 nT.

The MAG experiment weighs 7 kilograms and uses 3.9 watts of power.

Plasma Instrument



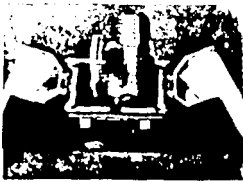
As remarked before, plasma consists of electrically charged particles—ions, which carry a positive charge, and electrons, which carry a negative charge. Usually, the number of ions in a plasma equals the number of electrons, so the plasma as a whole is electrically neutral, but ions and electrons travel different paths within the magnetosphere. The plasma instrument (PI.S) measures the energies and directions of approach of ions and electrons comprising the plasma. PI.S also uses a mass spectrometer to identify the composition of the ions.

Information from PI.S helps determine the temperature of the plasma and the manner in which the particles are distributed in space. This information in turn helps scientists understand particle dynamics in the magnetosphere, for example, where particles are being lost and where particles are being energized.

The PLS uses seven fields of view to collect charged particles for energy and mass analysis. These fields of view cover most angles from 0 to 180 degrees, fanning out from the spin axis. The rotation of the spacecraft carries each field of view through a full circle. The PLS will measure particles in the energy range from 9 volts to 52 kilovolts.

The PLS weighs 13.2 kilograms and uses an average of 10.7 watts of power.

Energetic Particles Detector



The energetic particles detector (EPD) is designed to measure the numbers and energies of ions and electrons whose energies exceed about 20 keV. (An electron volt, eV, is the unit of energy equal to the energy that an electron acquires in falling through an electrical potential of 1 volt.) The EPD can also measure the direction of travel of such particles and, in the case of ions, can determine their composition (whether the ion is oxygen or sulfur, for example).

The EPD uses silicon solid-state detectors and a time-of-flight detector system to measure changes in the energetic particle population at Jupiter as a function of position and time. These measurements will tell us how the particles get their energy and how they are transported through Jupiter's magnetosphere.

The EPD weighs 10.5 kilograms and uses 10.1 watts of power on average.

Plasma Wave Subsystem



Particles of plasma are bound to the magnetic field. Motions within the plasma can perturb the surrounding magnetic and electric fields. Changes with time of the electric and magnetic fields within plasma are called "plasma waves." There are a great many different sorts of waves that affect a plasma or are excited by a plasma. Some of these waves can cause particles to be lost from the magnetosphere. The Plasma Wave Subsystem (PWS) is designed to measure the properties of varying electric fields over the frequency range from 5 hertz to 5.6 megahertz and of varying magnetic fields from 5 hertz to 160 kilohertz-- and to identify the plasma waves present.

An electric dipole antenna (a simple antenna of the form that one often sees to improve radio reception on Earth) will study the electric fields of plasmas, while two search coil magnetic antennas will study the magnetic fields. The electric dipole antenna is mounted at the tip of the magnetometer boom. The search coil magnetic antennas are mounted on the high-gain antenna feed. Nearly simultaneous measurements of the electric and magnetic field spectrum will allow electrostatic waves to be distinguished from electromagnetic waves.

The PWS weighs 7.1 kilograms and uses an average of 9.8 watts.

Dust Detector Subsystem



"Dust" is a term used by astronomers to describe small grains of matter found not only in planetary systems but also in interstellar space, often mixed in with interstellar clouds of gas. Dust can be a natural part of the magnetosphere, or it can come from Jupiter, the satellites, or even from external forces like Comet Shoemaker-Levy 9.

The Dust Detector Subsystem (DDS) will be used to measure the mass, electric charge, and velocity of incoming particles. The masses of dust particles that the DDS can detect go from 10^{-16} to 10^{-7} grams. The speed of these small particles can be measured over the range of 1 to 70 kilometers per second. The instrument can measure impact rates from 1 particle per 115 days to 100 particles per second. These particles will help determine dust origin and dynamics within the magnetosphere.

The DDS weighs 4.2 kilograms and uses an average of 5.4 watts of power.

Engineering Experiment

Heavy Ion Counter

The heavy ion counter (HIC) experiment was originally included on the payload as an engineering experiment. It was to measure and monitor very high-energy heavy ions (such as the nuclei of oxygen atoms) hitting the spacecraft.

These measurements would then provide basic information on a form of radiation that can cause random changes in a spacecraft's electronics and perhaps provide the basis for the design of better radiation resistant electronics for future missions. However, scientists soon realized that the HIC data were useful to them as well. For example, the heavy ions observed by the HIC during solar flares have been analyzed to determine the composition of the Sun.

The HIC is really a repackaged and updated version of some parts of the flight spare of the Voyager Cosmic Ray System. The HIC detects heavy ions using stacks of single-crystal silicon wafers. The HIC can measure heavy ions with energies as low as 6 MeV and as high as 200 MeV per nucleon (that would be 3200 MeV for sulfur's charge of 16). This range includes all atomic substances between carbon and nickel.

The HIC and the EUV share a communications link and, therefore, must share observing time.

The HIC weighs 8 kilograms.

Radio Science

There are two scientific experiments that use Galileo's radio telecommunications system. "Radio science" has been used for several decades within the space science community to denote experiments conducted in this manner. The two categories of radio science that will be done at Jupiter are celestial mechanics and radio propagation.

Celestial Mechanics

The celestial mechanics experiments use the radio system to sense small changes in the trajectory of the spacecraft. The spacecraft's radio transmitter sends a signal at a well-known stable frequency. Any change in speed that the spacecraft experiences will cause the frequency of the radio signal received on Earth to change. The amount of change is dependent on the change in speed of the spacecraft, relative to Earth. When the spacecraft passes close to Jupiter or one of the Galilean satellites, that body pulls on the spacecraft, causing its speed to change. The amount of change in speed depends on] y upon the mass of the body and the distance of the spacecraft from that body. Thus, by measuring the change in frequency of the Earth-received radio signal, the mass of Jupiter or one of the Galilean satellites can be estimated.

The results should allow us to make a better selection of models for the interior of the satellites. This is possible because Galileo will approach the satellites much closer than did any earlier spacecraft, so that gravitational effects will be stronger and easier to observe. Arrival Day data have already confirmed that Io has a giant iron core. (See the Arrival at Jupiter section for more of the latest science news on Io.)

Radio Propagation

The spacecraft radio signal will be used to investigate Jupiter's neutral atmosphere and ionosphere, Io's ionosphere, and to search for ionospheres on the other Galilean satellites (Europa, Ganymede, and Callisto). This is done during radio occultation experiments, when the Galileo orbiter passes behind the planet or satellite as viewed from Earth.

The radio signal propagating from the spacecraft to Earth experiences both refraction and scattering in the atmosphere of the occulting body. (The atmosphere will bend and slow the radio signal by the process of refraction; additionally, the atmosphere will diffuse the electromagnetic waves of the signal by the process of scattering.) This causes changes in the frequency and amplitude of the signal received at a DSN tracking station on Earth. Analysis of these changes will yield information about the atmospheres and ionospheres of the Jovian system.

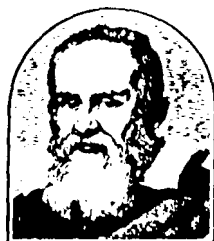
Anticipated results include profiles of electron number density versus radius in the ionosphere--- and profiles of refractive index, pressure, and temperature versus radius in the neutral atmosphere. Of particular importance will be the multiplicity of measurements of Jupiter's ionosphere at a variety of latitudes and magnetic longitudes.

The 18-month tour of the Jovian system includes 8 occultations of the spacecraft by Jupiter and more than 10 occultations by the four Galilean satellites.

*Principal
Investigators for the
Orbiter's Scientific
Experiments*

<u>Instrument</u>	<u>investigator</u>	<u>Objectives</u>
<u>Remote Sensing</u> (despun)		
SSI	Michael Belton NOAO	Galilean satellites, high resolution, atmospheric small-scale dynamics
NIMS	Robert Carlson JPL	Surface/atmospheric composition thermal mapping
PPR	James Hansen Goddard Institute for Space Studies	Atmospheric particles, thermal/reflected radiation
UVS/EUV	Charles Herd University of Colorado	Atmospheric gases, aerosols, etc.
<u>Fields and Particles</u> (Spinning)		
MAG	Margaret Kivelson UCLA	Strength and fluctuations of magnetic fields
EPD	Donald Williams Johns Hopkins APL	Electrons, protons, heavy ions
PLS	Paul Frank University of Iowa	Composition, energy, distribution of ions
Pws	Donald Gurnett University of Iowa	Electromagnetic waves and wave particle interactions
DDS	Eberhard Grün Max Planck Institut für Kernphysik	Mass, velocity, charge of submicrometer particles
<u>Engineering Experiment</u>		
HIC	Edward Stone Caltech	Spacecraft charged-particle environment
<u>Radio Science</u>		
Celestial Mechanics	John Anderson JPL	Masses and internal structures of bodies from spacecraft tracking
Propagation	W. L. Taylor Stanford University	Satellite radii and atmospheric structure from radio propagation

SECTION 5



THE GALILEO PROBE

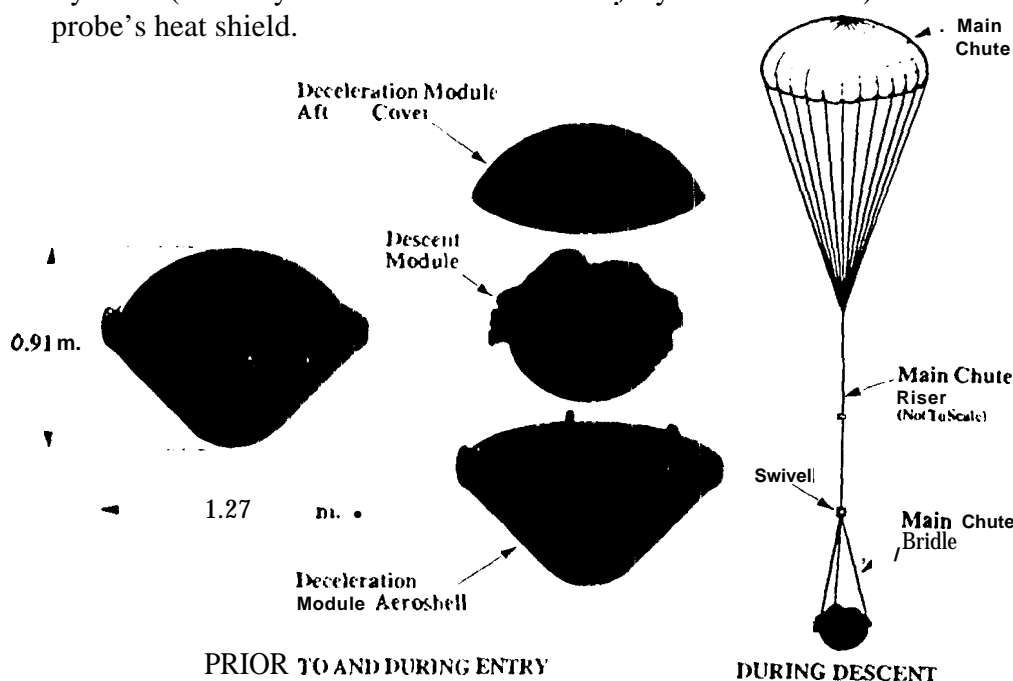
On Arrival Day, the Galileo probe achieved essentially all its mission objectives. It had been designed and built to sample and measure Jupiter's atmosphere (see Probe Science Results section). The probe, with a mass of 339 kilograms, was carried aboard the orbiter until its release in July 1995 for entry into the Jovian atmosphere on December 7, 1995. The probe carried a complement of six scientific instruments from which data were sent to the orbiter for relay to Earth.

The probe did not have an engine or thrusters so it could not change the path set for it by the orbiter. The probe was spin-stabilized, achieved by spinning the orbiter up to 10.5 rpm before release. "There was no communication between orbiter and probe during the coast to Jupiter because the probe had no capability to receive radio signals. And it could only transmit after atmospheric entry.

The probe consisted of two main parts, the deceleration module and the descent module. The deceleration module was required for the transition from the vacuum and cold of interplanetary space to the intense heat and structural loads to be incurred during a hypersonic entry into a planetary atmosphere—and from a speed of tens of kilometers per second to a relatively placid descent by parachute. The descent module was the part that carried the scientific instruments and supporting engineering subsystems that collected and transmitted priceless scientific data to the orbiter flying overhead.

The probe was managed by NASA's Ames Research Center. Hughes Space and Communications Company (formerly Hughes Aircraft Company) designed and built the probe, Lockheed Martin Hypersonic Systems (formerly General Electric Re-Entry Systems Division) built the probe's heat shield.

The Galileo Probe



**Deceleration
Module**

At entry, the probe's exterior resembled a blunt cone with a base 1.3 meters in diameter and a conical (half) angle of 45 degrees. The shape followed closely the design of the Pioneer Venus large probe.

The high-speed entry of a probe requires protection from the heat of entry. Heat shields have been used for this purpose since the early days of the space program. The materials used for the Galileo probe's two heat shields—carbon phenolic for the forebody shield and phenolic nylon for the afterbody shield—have been widely used for Earth re-entry vehicles. Temperatures of 14,000 kelvin were generated during the Galileo probe's entry into the Jovian atmosphere. For comparison, the surface temperature of the Sun is about 6000 kelvin.

The parachutes were used for two key functions, separating the deceleration and descent modules and providing an appropriate rate of descent through the atmosphere. Before deployment of the main chute, a smaller, pilot parachute was fired at 30 meters per second by a mortar to start the deployment process. The deployment occurred in less than 2 seconds, pulling away the aft cover and unfurling the main chute. The main parachute's diameter was 2.5 meters. The canopy and lines were made of Dacron and Kevlar, respectively. Once the main chute was fully deployed, the forebody shield (aeroshell) was jettisoned.

**Descent
Module**

The Galileo descent module, carrying the six scientific instruments, was not hermetically sealed against the influx of the Jovian atmosphere (unlike those designed for Pioneer-Venus). The need to save weight was a factor in this decision. However, certain equipment was hermetically sealed within housings designed to withstand pressures up to 20 bars and tested to 16 bars.

The bar is a unit of pressure, approximately equal to the atmospheric pressure of the Earth at mean sea level. (The Greek word "barys" means "heavy.") One often sees terrestrial weather data expressed in millibars (1 000 millibars equal 1 bar), abbreviated "mb."

**Engineering
Subsystems**

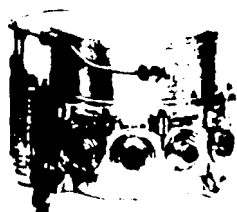
The engineering subsystems of the probe were those systems that maintained the scientific instruments in good health; furnished their commanding, thermal, and electrical needs during descent through the atmosphere; and processed and transmitted the resultant scientific data to the orbiter. To eliminate single-point, catastrophic mission failures, the probe was designed with redundant electrical and electronic subsystems. Two simultaneous data streams flowed from the instruments to the orbiter.

Communications Subsystem	<p>The communication subsystem provided two J -band channels. (J -band is a region of the radio spectrum is effective for transmission through Jupiter's atmosphere.) The two channels for the probe were at 1387.0 and 1387.1 megahertz. Both channels transmitted their signals through a crossed-dipole-pair antenna.</p> <p>The relay radio hardware (RRH) facilitated the communications link with the probe. Mounted on the orbiter, the RRH antenna was a 1.1 -meter, steerable, parabolic dish. The RRH digital receivers tracked the highly dynamic probe signals and processed them for storage on the orbiter's tape recorder and extended computer memory.</p>
Power Subsystem	<p>Once free from the orbiter, the power for the probe came from chemical energy stored in three battery modules, containing lithium/sulfur dioxide (LiSO₂) cells. (These batteries had about 22 amp hours; your car battery might have about 1/20th as much.) Additionally, a redundant set of thermal batteries provided the high-amperage current to fire the pyrotechnic hardware required during entry deployment events. The Power Subsystem also controlled energy distribution to the engineering subsystems and scientific instruments.</p>
Command and Data Handling Subsystem	<p>As the name indicates, the Command and Data Handling (C&DH) Subsystem refers to the two primary information components of a space mission: commands and data. The C&DH Subsystem consisted of the data and command processor, the pyrotechnic control unit, and the acceleration switches. En route to Jupiter, it processed and interpreted commands from the orbiter during probe tests, some of which were done just prior to separation.</p> <p>After separation, the Command and Data Handling Subsystem was in charge of issuing all commands internal to the probe. However, the probe was intentionally placed in a quiescent state during its 5-month coast period. During this interval, only the coast timer circuitry was powered,</p> <p>At the end of the coast, 6 hours before atmospheric entry, the timer wound down to zero and "woke up" the probe. During the descent through the atmosphere, a sequence of commands stored in non-volatile, read-only memory was executed. In conjunction with the design philosophy mentioned above, two electronic "strings" (or channels) were implemented in the Command and Data Handling Subsystem. Prior to entry, a self-test function was exercised. The probe's computer successfully passed this test.</p>

The Science instruments

The science instruments directly sampled the atmosphere and near-Jovian environment on the day of Galileo's arrival at Jupiter.

Atmospheric Structure Instrument



The primary purpose of the atmospheric structure instrument (ASI) was to determine how the temperature, pressure, and density of the atmosphere vary with altitude. The ASI was designed to take measurements from about 1000 kilometers above the clouds down to the end of the probe mission.

The instrument package consisted of acceleration, temperature, and pressure sensors and associated electronics. The temperature sensor had a range from 0 to 500 kelvin. (The mean temperature on Earth's surface is approximately 300 kelvin or 80 degrees Fahrenheit.) The pressure sensor was designed to cover a wide range of pressures from 0.1 to 28 bars. The pressure sensors were similar to devices used on the two Viking missions to Mars. Their reliability had been demonstrated through operation on the surface of Mars for several years.

The third type of sensor in the ASI, accelerometers, covered a wide range of measurements: from one millionth of a g to 400 g. (A "g" is the acceleration that gravity produces at the surface of the Earth and is equal to 9.8 m/s^2 .) Accelerations are sensed in three dimensions so that the total acceleration of the package is known. Acceleration data yield information about the effect of atmospheric turbulence on the probe.

The experiment mass was 4.1 kilograms, and the average experiment power was 6.0 watts.

Neutral Mass Spectrometer



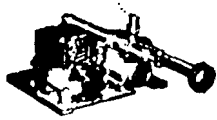
The composition of the atmosphere of Jupiter had been studied intensively with ground- and space-based observations, but many questions remained. The neutral mass spectrometer (NMS) was designed to provide a detailed analysis of the chemical composition of the atmosphere and aid in understanding the processes responsible for the complex, colorful clouds.

The Galileo probe uses a quadrupole mass spectrometer. In this device the ions are passed between four parallel rods. These rods have a combination of DC and AC voltages that allows ions of a certain mass to pass through, while rejecting the rest. During descent, the voltages are adjusted to allow different masses to pass through.

Atmospheric gases entered the mass spectrometer through two inlet ports at the apex of the probe. These ports were sealed by metal-ceramic devices and kept under a vacuum until the probe entered the atmosphere. Pyrotechnic devices then released the covers, allowing atmospheric gases to enter and be pumped to the test cells.

The instrument weighed 13.3 kilograms and consumed about 25 watts.

Nephelometer



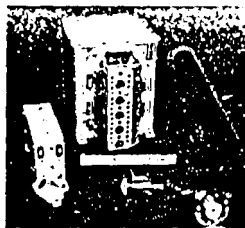
The nephelometer (NEP) was used to investigate the structure of clouds and the characteristics of particles in the atmosphere of Jupiter. (In Greek, the word “nephelē” means “cloud.”) Knowledge of cloud properties allows modeling of the paths of energy balance for Jupiter.

The detailed scientific objectives of the NEP are tied to altitude, as measured by pressure, within the atmosphere. The NEP was designed to map cloud structures to a resolution of 1 kilometer from 0.1 to 10 bars. Also, the NEP measured the number and dimensions of particles and determined, by their shape, whether they were in the liquid or solid (ice) state.

The NEP fired a laser beam from the probe through cloud particles adjacent to the probe. A detector on an arm extended away from the probe measured the scattered light at different angles.

The instrument mass weighed 4.7 kilograms and operated on an average of 11 watts.

Lightning and Radio Emissions Detector/ Energetic Particles instrument



For the lightning and radio emissions detector/enrgetic particles instrument (LRD/EPI) investigation, two instruments shared the electrical system that collected the LRD data— together with the scaling, data processing, and data formatting of the EPI.

The LRD searched for lightning during its descent through the atmosphere of Jupiter and also measured the radio-frequency noise spectrum of the atmosphere (the amount of radio energy as a function of frequency). In addition, the LRD made radio-frequency measurements as the probe approached Jupiter, at about 4, 3, 2, and 1 planetary radii.

The LRD hardware consisted of three basic sensors. One sensor was a radio-frequency antenna that measured in the frequency range from 10 hertz to 100 kilohertz. The lightning sensors operated in the optical range. Two sensitive photodiodes were placed behind two fisheye lenses that looked out perpendicular to the spin axis of the probe, 180 degrees apart, to give full coverage.

The EPI experiment studied the inner portion of the magnetosphere (the region within 5 radii of the planet) and the outer reaches of the Jovian atmosphere. The objects of this study were four species of particles: electrons, protons, alpha particles, and heavy ions (atomic number greater than 2). (An alpha particle is the nucleus of a helium atom, which is composed of two protons and two neutrons.)

The EPI made omnidirectional measurements of particles. Samples were taken at 5, 4, and 3 Jupiter radii, then continuously from 2 radii to entry of the atmosphere. The EPI could count up to as many as 3 million particles per second.

The EPI's silicon detectors were mounted at the end of a telescope tube. The telescope was aligned at an angle of 4) degrees to the spin axis of the probe.

The experiment mass was 2.9 kilograms, and average power was 3 watts.

Helium Abundance Detector



The atmosphere of Jupiter is composed primarily of hydrogen and helium. The helium abundance detector (HAD) had the ability to measure very accurately the abundance ratio of helium to hydrogen. The uncertainty in the ratio was expected to be 0.0015, more than 10 times smaller than the best current Voyager uncertainty.

The optical properties of a substance are a function of its composition. The HAD instrument made the measurement of the abundance ratio by determining the refractive index of the Jovian atmosphere over a range of pressures from 2.5 to 10 bars. The measurements were done using an optical interferometer.

The mass was 5 kilograms, and the instrument consumed 1 watt.

Net Flux Radiometer



Pioneer and Voyager spacecraft passing by Jupiter measured radiation leaving Jupiter's cloud tops, but we could only guess about the nature of radiation within the atmosphere. In contrast, the net flux radiometer (NFR) in the probe was designed to directly sample the local energy flows within and below the Jovian cloud layers.

As the probe descended through various atmospheric layers, observable changes in the net radiation flux were anticipated. The temperature differences that tend to arise from the radiative heating and cooling would produce buoyancy differences and, ultimately, winds. During the descent into a continuously hotter and denser atmosphere, the NFR rapidly alternated between looking upward and looking downward. Measuring the difference in radiation intensity between these two views would determine the amount and direction of the net flow of radiative energy.

Radiation from the Jovian atmosphere entered the instrument through a diamond window. The NFR had six lithium tantalate pyroelectric

detectors viewing through filters extending, from the visible to infrared wavelengths.

The NFR had a mass of 3.4 kilograms and used an average of 13 watts during descent,

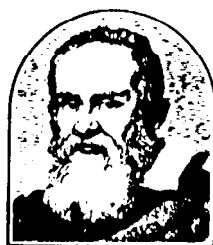
Doppler Wind Experiment

The Doppler wind experiment (DWE) measured the winds in the atmosphere of Jupiter by using the Doppler effect. As the probe was buffeted by winds during the descent, the frequency of its radio signal changed, indicating the probe's velocity and providing data about the winds. Voyager data showed winds of 100 meters per second (about 200 miles per hour) at the top of the clouds. An analysis of the Doppler effect on the probe radio signal can tell us about winds deeper in the atmosphere and the source of energy that drives them. Is the source solar or does it come from heat welling up from the planet itself?

Probe Scientific Experiments

Experiment	Principal investigator, institution	Objectives
Atmospheric Structure	Alvin Seiff, San Jose State University Foundation	Temperature, pressure, density, molecular weight profiles
Neutral Mass Spectrometer	Hasso Niemann, NASA Goddard	Chemical composition
Helium Abundance	Ulf von Zahn, Institut für Atmosphärenphysik an der Universität Rostock	Helium/hydrogen ratio
Nephelometer	Boris Ragert, San Jose State University Foundation	Clouds, solid/liquid particles
Net Flux Radiometer	Larry Stromovsky, University of Wisconsin	Thermal/solar energy profiles
Lightning and Radio Emissions/Energetic Particles	Louis Lanzerotti, Bell Laboratories, and Klaus Rinnert, Max Planck-Institut für Aeronomie Harald Fischer, Institut für Reine und Angewandte Kernphysik, Universität Kiel	Detect lightning, measure energetic particles
Doppler Wind Experiment	Dave Atkinson, University of Idaho	Measure winds, learn their energy source

SECTION 6



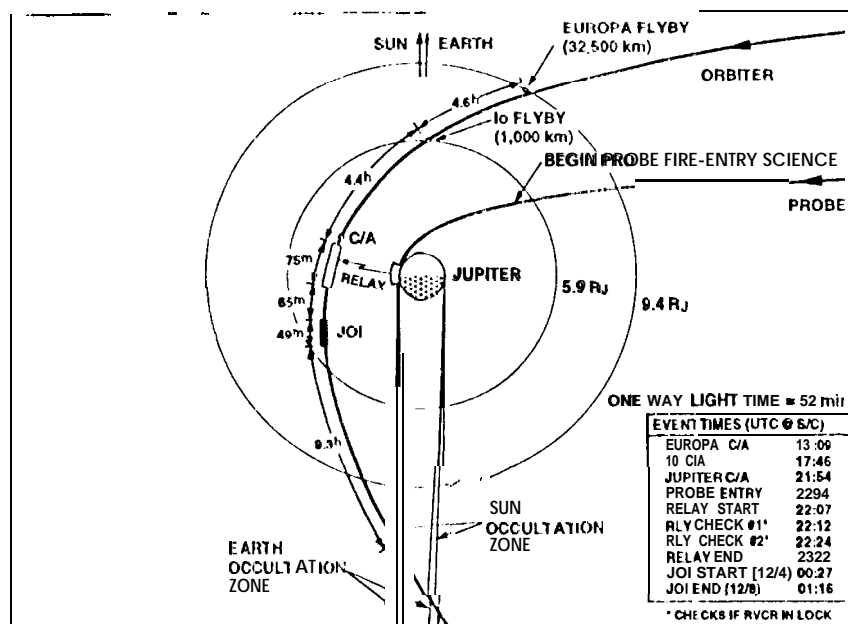
ARRIVAL AT JUPITER

It was a day of anticipation- tension too-- as the men and women of Project Galileo watched and waited. The presence of NASA dignitaries; friends and families; and the press, super-tecl by television crews, contributed to the excitement. Data telling the story of events happening over 900 million kilometers away took 52 minutes (the one-way light time for a radio signal to traverse the space between Jupiter and Earth) to be received by the Jet Propulsion Laboratory via the Deep Space Network stations. During the long day, experts analyzed the precious stream of data; then commentators vividly portrayed the news of spacecraft and probe activity for viewing on television monitors throughout the Laboratory. Word of the ongoing success of the mission circled the globe, headlined in newspapers and television. By evening, the celebration was on. All had gone well. There had been no surprises!

So Much To Do

The 24 hours of Arrival Day--December 7, 1995-- were the busiest of the whole mission. The orbiter flew close to two of the Galilean satellites, listened as the probe plunged into the atmosphere, and performed a large burn to slow itself down and get into orbit.

Arrival Day Events December 7, 1995



We Fly By Two Moons

The orbiter passed about 32,500 kilometers from Europa and will return for in-depth study three times during its 2-year stay in the Jovian system. Less than 5 hours after Europa, the orbiter flew by Io at about 900 kilometers (559 miles). Because of the tape recorder problem, no pictures (which require high tape recorder rates) were taken of either moon. For Io, especially, this is a great loss. (Currently, there is no plan for further close encounters because of the intense radiation, but Io will be monitored from intermediate ranges throughout the tour.) The tape recorder was able to record (at a low rate) fields and particles data on the Io plasma torus for 3 and 1/2 hours, ending 1/2 hour after closest approach. The tape recorder stopped 1/2 hour after the Io flyby and waited for the probe relay.

Io Has An Iron Core!

Yes, we now know the theory to be true. Io has an iron core. It is dense and gigantic, taking up half of the moon's diameter. Scientists took advantage of this closest approach by any spacecraft to conduct a celestial mechanics experiment (see Radio Science, The Galileo (h-biter) section). The pull of Io's gravitational field altered the orbiter's speed slightly, causing changes in frequency of the signal radioed to Earth. Analysis of the data indicates that Io has a two-layer structure, a metallic core (probably made of iron and iron sulfide) about 900 kilometers (559 miles) in radius, surrounded by partially molten rock and crust. The core was probably formed from heating in the interior of the moon, either when it originally formed or as a result of the perpetual tidal heating driving its volcanoes.

The Core Revealed



And A Magnetosphere?

Surprise! Besides verifying the existence of Io's core of iron, Galileo's fields and particles instruments detected a large bubble in Jupiter's magnetic field near this moon, a region where Jupiter's nominal magnetic field seemed to disappear. (In fact, the magnetic field (hanged orientation dramatically!) This phenomenon sometimes indicates that two magnetosphere's are in contact with one another. Now we wonder, "Does Io generate its own magnetospheric?" If so, it would be the only known moon to have one. There is also mounting evidence that Io is the source of the amazing high-velocity dust streams apparently coming from Jupiter.

A Close Approach

When the orbiter crossed 10's mbit, the probe had already been awakened from its 150-day cruise. An hour later, its first instrument (LRD/EPI) began measurements of the high energy particles encircling Jupiter. About 4 hours after leaving 10, the orbiter made its closest approach to Jupiter. The radiation was intense, perhaps 25 times more than is deadly for humans. In fact, a third of the total expected radiation dose for the whole 2-year tour at Jupiter might have been absorbed on this one day,

What really happened? Star scanner data suggested that the radiation flux had a different profile than prelaunch expectations. Further analysis can be made after we receive the Arrival Day fields and particles data (awaiting playback from the tape in mid-June). Meanwhile, there is no evidence of any radiation-induced anomalous effects; the spacecraft and its instruments have been and continue to perform normally.

Eight minutes after closest approach to Jupiter, the tape recorder started again in preparation for storing probe data and engineering data from the Jupiter orbiter insertion (JOI) maneuver. The orbiter was 215,000 kilometers (134,000 miles) above the probe—ready for the radio relay.

The Probe Descent

Three minutes later, the sturdy probe withstood a structural load 230 times the acceleration force of Earth gravity as it slammed into the top of Jupiter's atmosphere at the comet-like speed of 170,000 kilometers per hour (106,000 miles per hour). Almost 3 minutes into entry, the probe had slowed enough to deploy its parachutes and drop what was left of the heat shield, exposed to temperatures twice as hot as the Sun's surface. (The parachute deployment occurred nearly a minute late.)

Thirty-five seconds later, the probe began to transmit its data (much of it redundant) to the orbiter at 128 bits per second per string, (channel). The probe transmitted reports on the sunlight and heat flux, pressure, temperature, lightning activity, winds, and composition and structure of the atmosphere, as well as energetic particles measurements acquired during pre-entry. Only traces of the anticipated ammonia and ammonium hydrosulfide cloud layers were actually detected.

Some 8 minutes after it entered the atmosphere, the probe was expected to approach the tops of water clouds, but none were encountered. The probe experienced stronger winds than expected, but only slight evidence of distant though very intense lightning.

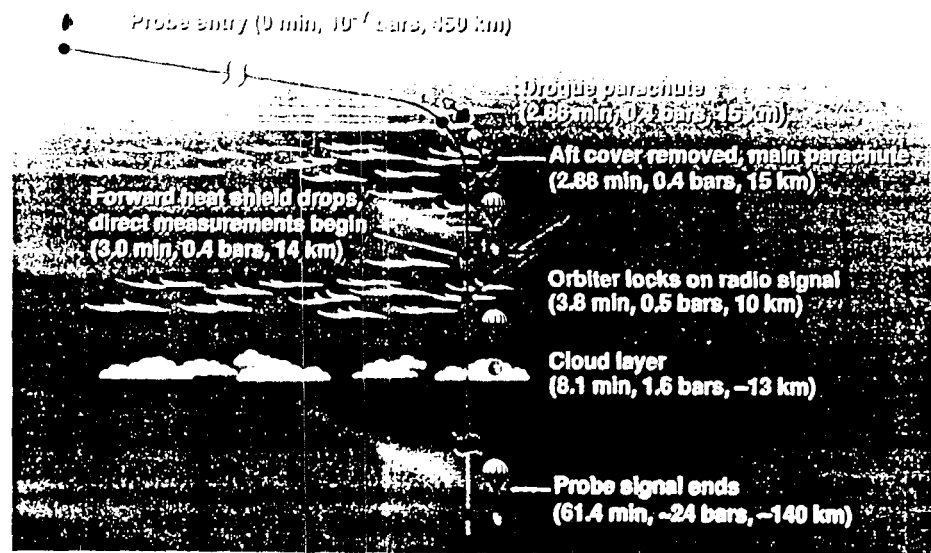
The probe's internal temperature was more closely coupled to that of the atmosphere than had been expected. Consequently, the science instrument temperatures exceeded operational limits. Nevertheless, all the instruments worked. To confirm the accuracy of the data acquired by the instruments at lower altitudes and under these extreme conditions, scientists plan to recalibrate some of the flight spares, tested to the actual temperature profile experienced by the probe.

Thirty-two minutes past entry, the orbiter's articulated relay radio antenna slewed to compensate for the probe's changing position below it. The spacecraft slewed three more times at 10-minute intervals to maintain lock. The probe continued to transmit data for 57.6 minutes until the 24-bar level (152 degrees Celsius and 140 kilometers below the 1-bar pressure level).

The Fate of the Galileo Probe

Scientists believe that as it continued to fall into the planet after completion of its mission, the probe melted, then evaporated in the intense heat (at the 5000-bar level, 1700 degrees Celsius). It was reduced to its atomic components and is now one with the atmosphere of Jupiter.

The Probe Fulfills Its Mission



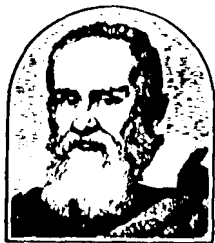
**JOI—
A Critical
Maneuver**

Unlike other maneuvers the orbiter had done, there was only one chance to get JOI right. An error could have sent Galileo into faraway space! The orbiter spun up to 10.5 rpm as soon after completion of the probe relay as possible to guarantee orientation and stability during the burn. The orbiter then fired the 400- newton engine to slow its speed by 643 meters per second. The burn, which began 73 minutes after the end of probe relay, lasted 49 minutes. The expert DSN tracking, on-target navigation (without the use of optics, since imaging had been eliminated during approach), and a perfect JOI placed Galileo in the desired orbit.

**Earth
Occultation**

Nine hours after engine cutoff, Earth disappeared behind the disk of Jupiter. Fifty minutes later, the Sun passed behind Jupiter, too, and the orbiter was in darkness for the first time in years. Finally, after 3 and 1/2 hours of radio silence, the Earth reappeared to the orbiter, and contact was reestablished. The Sun reappeared 47 minutes later. The orbiter was now on its 7-month first orbit in the Jovian system. Galileo had arrived!

SECTION 7

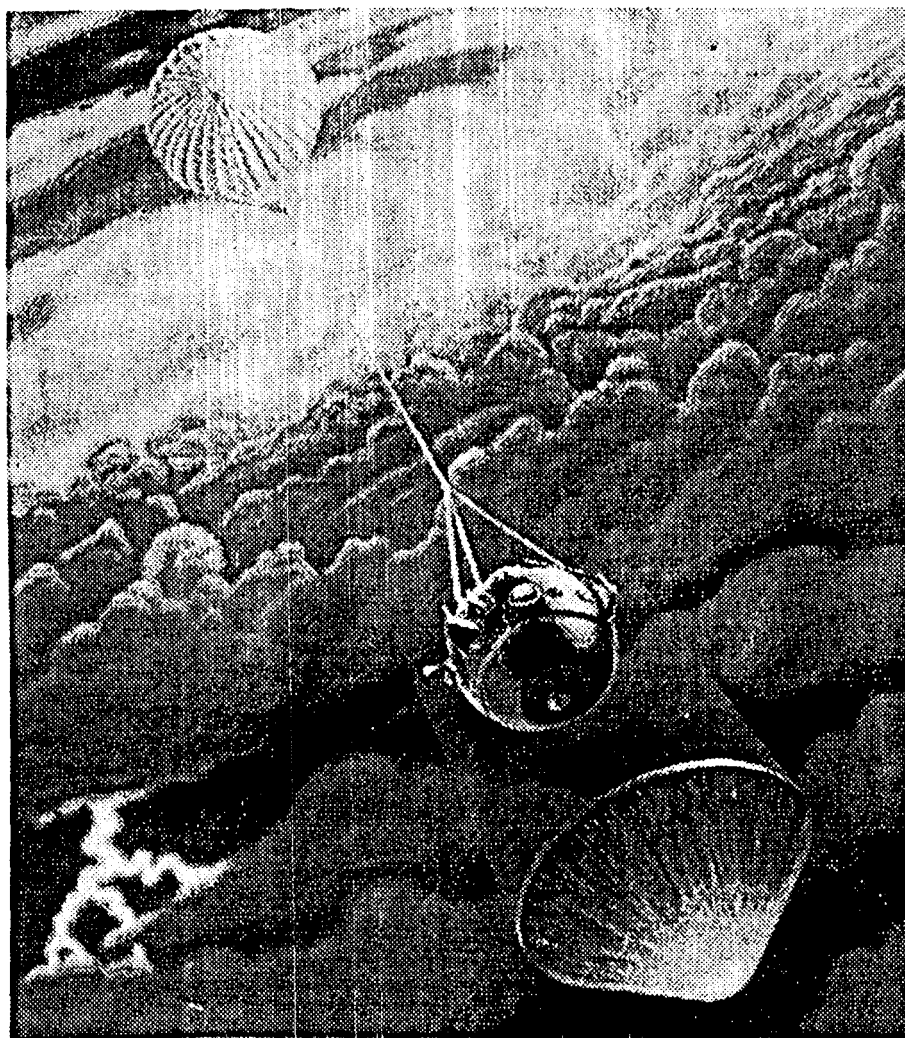


PROBE SCIENCE RESULTS

Under surveillance, by telescopes here on Earth as well as the Hubble Space Telescope, the observations show that the probe apparently entered the highly variable atmosphere of Jupiter near the southern edge of an infrared "hot spot." All the instruments operated successfully. The return of the probe mission data, stored on the orbiter's computer memory and in the tape recorder, was completed on April 15 and April 20, respectively. Scientists reported their preliminary results at a January 22 press conference. By March 18, 1996, in time for the Lunar and Planetary Science Conference in Houston, Texas, they had arrived at their current understanding.

What did we learn from the probe data? Comprehensive analysis will take years. At this time, we can look at the preliminary findings; they give us some answers to the character of Jupiter's atmosphere--and even more questions.

*An Artist's View of
the Probe's Descent*



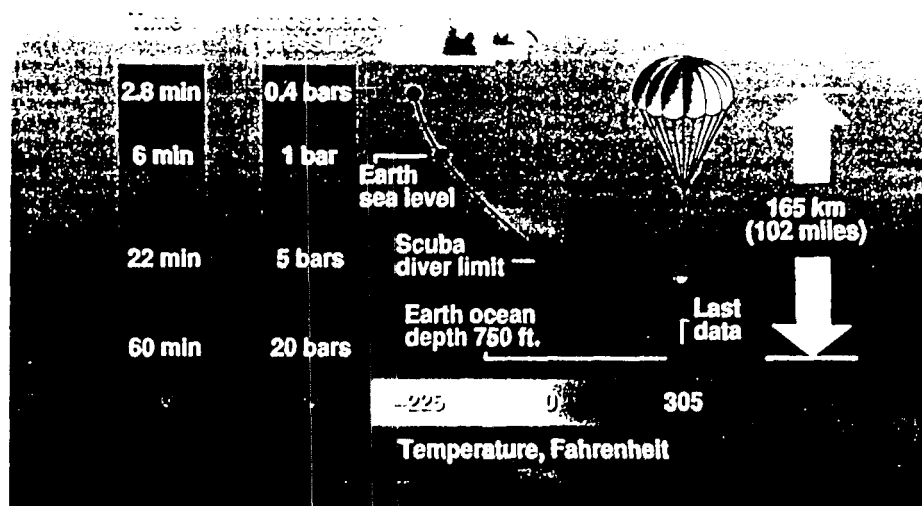
NASA Ames Research Center

Atmospheric Structure

The pressure, temperature, and density structure measurements by the atmospheric structure instrument (A S1) during descent are fundamental to understanding Jupiter's atmosphere and essential in the interpretation of results from the other experiments. Evidently, the atmosphere of Jupiter is much drier than anticipated, based on other data (Voyager and comet Shoemaker-1 .cvy 9). Rather than finding a water abundance twice that of the Sun (based on the Sun's oxygen content), it appears that the water abundance of the Jovian atmosphere is less than or about one-fifth that of the Sun.

Temperatures in the upper reaches of the atmosphere were much higher than could be accounted for if sunlight were the only heating source; some other source of heat must exist. Pressure readings in the upper atmosphere also show a region more dense than predicted. In the lower regions, temperature increased with pressure about as expected, although at a slightly lower rate. This implies that deeper regions of Jupiter's atmosphere may not be convective as previously thought. Scientists look to the probe data to better understand the influence of internal heat pouring forth from Jupiter's core.

Structure of Jupiter's Atmosphere



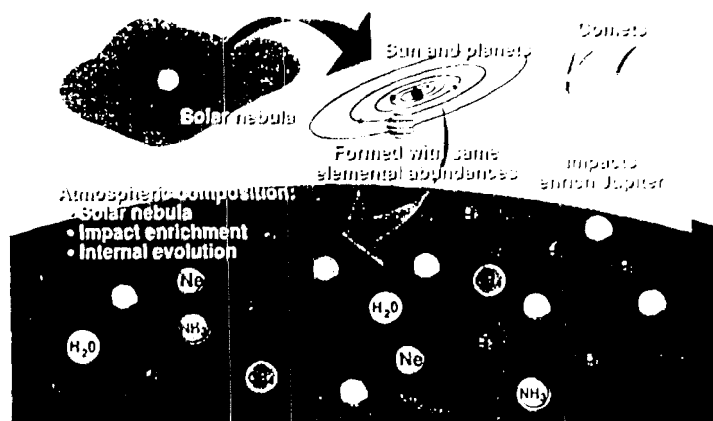
Helium Abundance

Data from the helium abundance detector (HAI) reveals that the mass ratio of helium to hydrogen is about 24 percent, close to the value of the primordial Sun—when the solar system was forming. The theory of planetary evolution must now take into account the fact that there has been little change in helium abundance in the Jovian atmosphere since the birth of the solar system. Also, helium has not rained down or settled toward the center of the planet as much as it seems to have done on Saturn, where the ratio is only 6 percent.

Chemical Composition

And what of the other one percent? The neutral mass spectrometer (NMS) detected the presence of heavy elements—carbon, nitrogen, and sulfur—suggesting that meteorites and other small bodies have contributed to the planet's composition. Few complex organic compounds (based on carbon and hydrogen) were evident so the likelihood of finding life as we know it here on Earth is extremely remote. Oxygen is highly depleted relative to the abundance on the Sun, a result that will force new ways of thinking about Jupiter's formation and evolution.

Composition: A Tracer for Planetary History



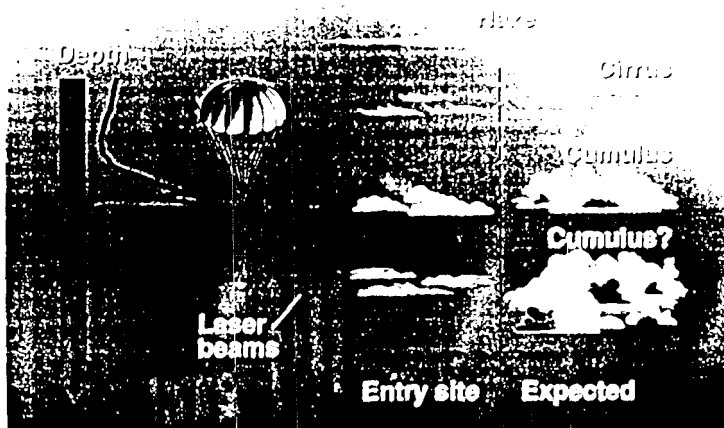
Clouds

The nephelometer (NEP) data surprised scientists. None of the expected thick, dense clouds were found! Concentrations of cloud particles and haze in the immediate vicinity of the probe were minimal. NEP's laser beam detected only one distinct cloud structure, possibly the expected ammonium hydrosulfide cloud layer. Yet observations from Earth and Voyager indicate that Jupiter is enshrouded with clouds. Scientists thought there would be three cloud layers: an upper layer of ammonia crystals, a middle layer of ammonium hydrosulfide, and a thick bottom layer of water and ice crystals. It may be that the probe site was not typical.

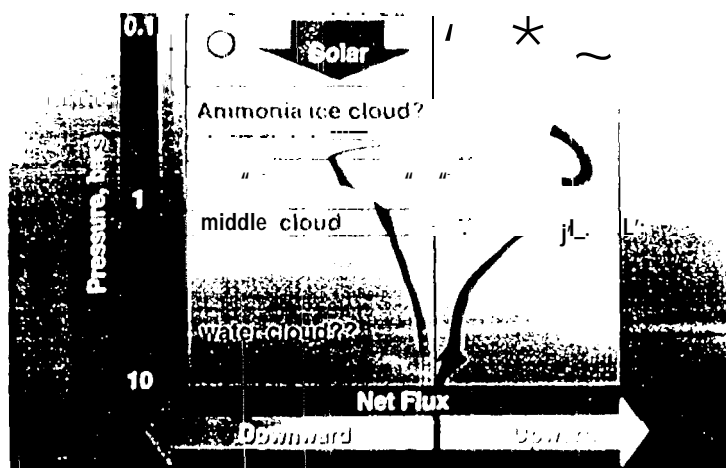
Thermal/ Solar Energy Profiles

The net flux radiometer (NFR) apparently detected the bottom part of the ammonia cloud layer by measuring the decrease in direct sunlight as the probe descended. These clouds would have been at some distance from the probe. The NFR infrared radiative flux channels measured energy fluxes consistent with the dry atmosphere.

Jupiter's Clouds



Net Radiation Fluxes



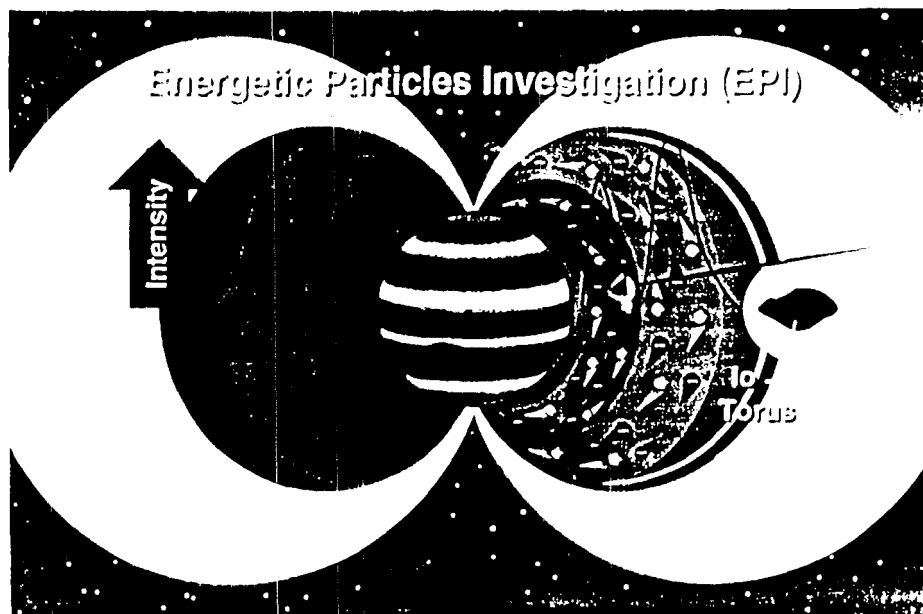
Lightning

The lightning and radio emission detector found no evidence of lightning flashes in the vicinity of the probe. Radio signals revealed distant discharges— perhaps one Earth diameter away but much stronger than those on Earth. Apparently lightning is 3 to 10 times less common per square kilometer per hour than on Earth. Since lightning is believed to produce organic compounds, these findings support the dearth of such molecules found by the neutral mass spectrometer.

A New Radiation Belt

As the probe passed through the region between Jupiter's ring and the upper atmosphere during the 3 hours before entry, the energetic particle instrument (EPI) made a surprising discovery. It detected high-energy helium atoms (source unknown) and a radiation belt about 10 times as strong as the Earth's Van Allen radiation belts. A study of this phenomenon will give scientists new insight into the high-frequency radio emissions from Jupiter and other objects in space that also have magnetospheres and trapped radiation.

Energetic Particles Investigation

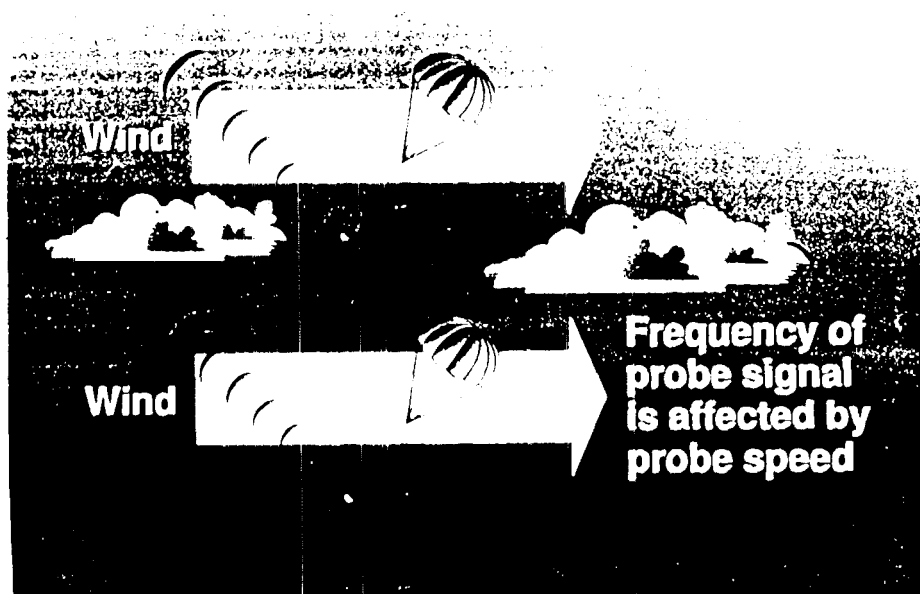


Strong Winds

Finally, the Doppler wind experiment indicated that zonal (east–west) wind speeds near clouds levels are about 540 kilometers per hour (330 miles per hour). Winds just as powerful exist at the top of the clouds, according to Hubble Space Telescope observations. Until the probe descent, the wind activity below the clouds had been hidden from view. Using the Doppler effect, the changes in the frequency of the radio signal from the probe as it floated downward amidst turbulent currents told the story of vertical variation in wind strength.

Toward the end of the mission, deep winds sustained 680 to 720 kilometers per hour (425 to 450 miles per hour). This consistency in wind speed suggests that the intense heat radiated from the interior of the planet is responsible for the strong winds.

The Doppler Effect



An Atypical Entry Site?

Were conditions at the probe entry point typical of the planetary environment? To find out more about this, the measurements acquired by the six probe instruments under these unique circumstances will be augmented by a broad range of data from orbiter science instruments during the Jovian tour.

SECTION 8

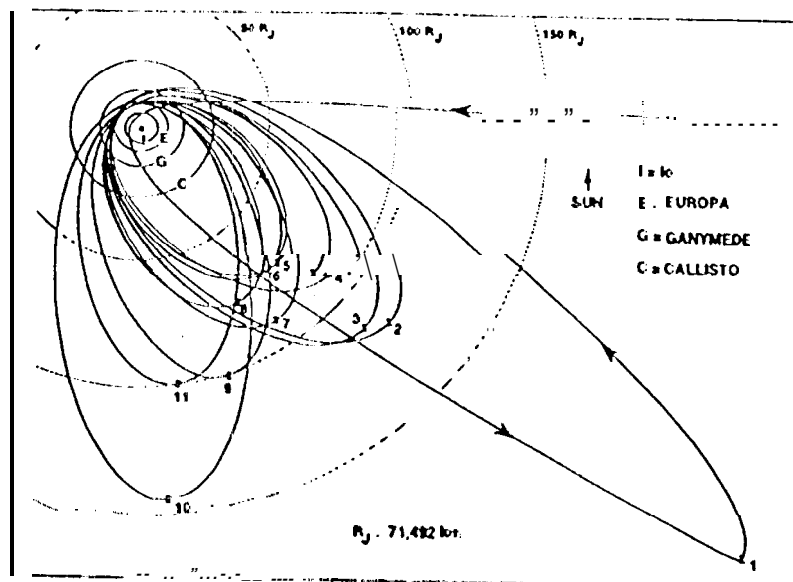


THE TOUR

The Jovian tour is a series of targeted encounters with the Galilean satellites. In preparation for the tour, the gravity assist from the Io flyby and the Jupiter orbit insertion (JOI) maneuvered the orbiter for the first, and by far the longest (nearly 7 months), highly elliptical path about the planet. Galileo is now on its way to a close encounter (500 kilometers) with Ganymede on June 27, 1996.

A glance at the figure below will show you the series of 11 flower-petal-shaped orbits for the tour. A total of four encounters at Ganymede, three at Europa, and three at Callisto are planned. After the first encounter, the orbits will be much shorter, and the time for each will range from 1 to 2.5 months. After the mission has been completed (December 1997), Galileo will continue to orbit Jupiter for probably thousands of years.

*Satellite Tour
Petal Plot*



A Typical Tour

Is . . .

First, how do we name an orbit? "OrbitMN" where "M" is the first letter of the moon (C, E, or G for Callisto, Europa, or Ganymede) and "N" numbers the orbits from 1 to 11 (the insertion orbit counted as zero)—actually names the set of observations and spacecraft activities performed during each satellite encounter period of the tour. G1 is the encounter at Ganymede and begins the second complete revolution around Jupiter. Since the orbit insertion maneuver, Galileo has been in the first orbit around Jupiter, J0, on its way to Ganymede. For a listing of the encounters, see the table below.

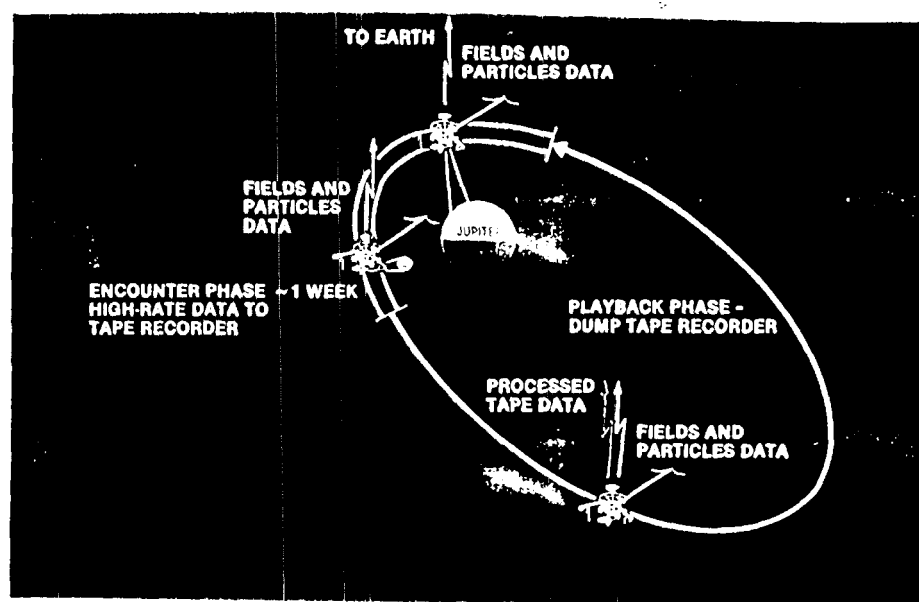
Tour Highlights

Orbit	Satellite Encounter	Date (UTC)	Altitude (km)	Altitude (miles)
1	Ganymede	June 27, 1996	844	524
2	Ganymede	September 6	250	155
3	Callisto	November 4	1104	686
4	Europa	December 19	692	430
(5)	(Solar conjunction)		(no close flyby)	
6	Europa	February 20, 1997	587	365
7	Ganymede	April 5	3059	1901
8	Ganymede	May 7	1585	985
9	Callisto	June 25	416	258
	Magnetotail Apojove	August 8		
10	Callisto	September 17	524	326
11	Europa	November 6	1125	699

The Orbiter At Work

What will the orbiter be doing during the satellite tour? Each orbit is divided into an encounter period of approximately one week and a cruise period of several weeks duration, the remainder of the orbit prior to the next encounter (see figure, Typical Orbit, -1 to 2 Months). During parts of each encounter period, Galileo will be recording data at high rates onto its tape recorder in addition to returning real-time fields and particles data. This recorded data will include images, ultraviolet and infrared spectra, and high-rate fields and particles measurements (especially around closest approach to the targeted satellite for that orbit). During the cruise period of the orbit, the recorded data will be played back to Earth, interspersed with real-time fields and particles data.

*Typical Orbit
-1 to 2 months*



The Science
Opportunity

The principal science elements for a typical orbit are remote sensing of the Galilean satellites and Jupiter atmosphere (performed primarily within a few days of each satellite encounter) and in situ measurements of the magnetosphere, acquired continuously but with higher resolution near the satellite encounter and during Galileo's trip down Jupiter's magnetotail (between C9 and C10). Most of the remote-sensing data will be recorded for playback between encounters, although some NIMS and UVS measurements are sent in the real-time stream. Fields and particles measurements, the core of the magnetosphere data, will also be recorded during encounter, as well as being edited for near-real-time inclusion in the downlink.

Three working groups—Atmospheres, Satellites, and Magnetospheres—have been established to meet the science objectives of the tour (see The Galileo orbiter section). Each group has its own focus and needs for acquiring and retrieving data. But as you can imagine, there are restrictions on just how much data is available for each discipline. So the working groups bargain and make trades to deal with the operational limitations imposed by the amount of tape recorder space available, the number of bits of data that can be returned to Earth prior to the following encounter, and the amount of spacecraft memory available to retain the observing/engineering sequences.

Aiming the Spacecraft

How will the Project Galileo team “steer” the spacecraft so that it will encounter the other Galilean moons? Rocket propulsion could have done the job, but the amount of propellant required to perform the maneuvers in Jupiter’s strong gravitational field would have added too much weight to the spacecraft. Remember VEGA? (See The Journey to Date section.) Yes, gravity-assist will be the answer. At each encounter, the gravitational force of the satellite will be used to alter the course of the orbiter—and this technique requires only a small amount of propellant to fine-tune the spacecraft path. The entire tour can be flown so that thrusters need to supply a change in speed of only about 100 meters per second, 60 times less than would otherwise be needed. We think of this trajectory design as a 10-cushion shot in a celestial billiard hall game! (If you could make very small corrections along the way.)

Both radio tracking and optical data are required to navigate the orbiter. Special navigation passes are provided three times a week and more often around orbit trim maneuvers (OTMs) and satellite encounters. Frequency depends on the spacecraft, the target body, and star geometry and on the OTM schedule (three OTMs per orbit). Post encounter (-13 days) will typically be used to correct the previous satellite encounter flyby energy. The maneuvers for apojove and before encounters (-3 days) are typically used to target to the next satellite encounter.

Getting a Lift!

This critical steering, of the spacecraft started in the very first orbit. The 400-newton engine was called upon for the third and last time to change the course of Galileo. On March 14, 1996, it performed the perijove raise maneuver (PJR). Like the same as with the ODM and JOI, the 400-newton engine did its job well, this time doubling the orbital speed of the spacecraft while it was at apojove, its greatest distance from the planet. And PJR raised the spacecraft from $4R_J$ to $9R_J$ (Jupiter radii) for its closest approach.

Why was this maneuver essential? As you know, Jupiter has an intense radiation belt that could damage the science instruments and the orbiter itself. Galileo was designed to withstand 150 krad, a lethal dose for humans. On arrival, the orbiter was subjected to this radiation hazard following the 10 flyby when it reached perijove (closest approach) at an altitude of 215,000 kilometers or about $3R_J$ ($4R_J$ from the center of the planet). There was no damage at that time (except for temporary radiation saturation of the star scanner), but repeated doses of radiation could and probably would be a different story. That is why PJR was performed. To limit further radiation exposure, PJR raised the perijove during the eleven tour orbits to near that of Europa’s orbit, about 600,000 kilometers above Jupiter.

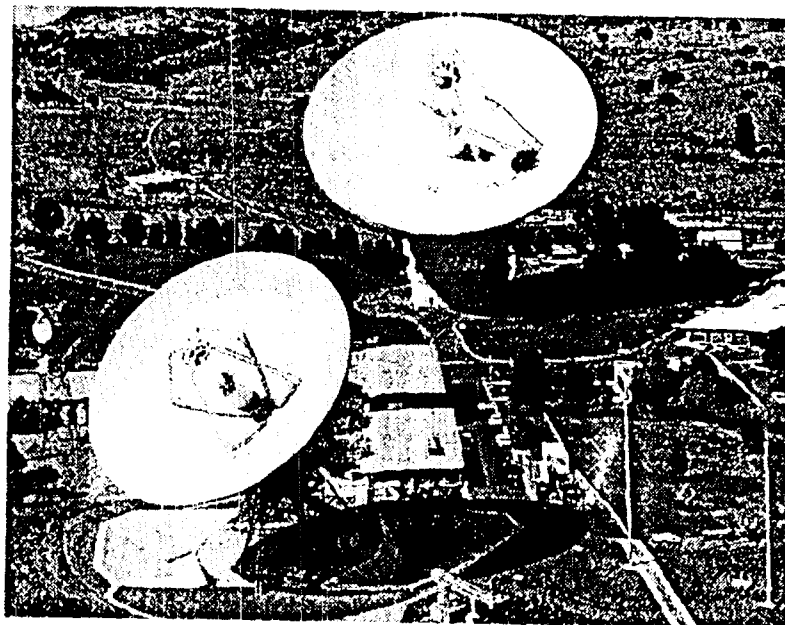
Pointing the Spacecraft

Other spacecraft housekeeping chores include attitude maintenance to keep the spacecraft pointing within 4 degrees of Earth for telecom link performance and engineering monitoring. Real-time engineering (RTE) data is supplied at either 12 or 10 bps (the lower rate is nominal). On most orbits, special turns of the spacecraft are planned to allow the scan platform instruments to view parts of the sky which are otherwise blocked by the booms or main body of the spacecraft. These turns are called "spacecraft inertial turns" or SITURNS, but they are more commonly known as "science turns." Targets that are enabled by SITURNS are Jupiter darkside observations, such as aurora, lightning, and ring observations. During the mission, 20 kilograms of propellant are budgeted for SITURNS; a typical 90 degree turn and return costs about 3 kilograms.

Tele- communications

Galileo's radio puts out about 20 watts of power, about the power of a refrigerator lightbulb. By the time it reaches the DSN antennas on Earth, a 70-meter antenna is able to scoop up only about one part in 10 to the 20th watt, in other words .00000000000000000001 watt. The Deep Space Network (DSN) stations at Goldstone, California; Madrid, Spain; and Canberra, Australia are ready. Canberra is in the best position for reception most of the time. Starting in November 1996, nearby Parkes radio telescope (not part of the DSN) will help boost coverage. New receivers, enhanced S-band reception, and the ability to array multiple antennas all contribute to the capability of receiving these tiny signals from the spacecraft. Not only will there be arraying of antennas at the Canberra site (see figure for Station 42 and 43; Station 34, not shown, is newly constructed), but also across continents when Goldstone is arrayed with Canberra.

*Arrayed Antennas at
Canberra*



Downlink

Galileo's radio signal to Earth, the downlink, can be thought of as a "pipeline." It is our only communication line and must carry all the navigation, engineering, and science data—real-time and recorded—to the DSN receivers for further analysis by Project Galileo.

New spacecraft software that improved telecommunications was uploaded in the spring of 1996 (see The Galileo Orbiter section, Spacecraft Subsystems, for the first software upload). This base 2 software modified most science instruments, the Command and Data Subsystem (CDS), the Attitude and Articulation Control Subsystem (AACS), and most of the Project Galileo ground data systems. The upgrade allows editing and compression of the science and engineering data streams and provided a buffering mechanism to manage the flow of data from real-time sources into the Data Memory System (DMS) tape recorder playback into the downlink channel. These changes will increase the 8- to 26-bits per second data transmission rate by 10 times.

The magnetospheric survey and parts of other high priority data sets require continuous real-time science data collected at rates ranging from 19.7 to 151.8 bps. These data are stored in the multi-use buffer (MUB) when the collection rate exceeds the telemetry rate--- and may place constraints on the playback process if a large part of the buffer is required. The MUB is a 41 kilobyte region in the CDS used to temporarily store raw real-time science data, raw playback data, and processed data prior to downlinking. Data compression contributes to the effective use of the downlink. Once data is in the MUB, Galileo's computer (the CDS), begins processing it, using instructions from the stored sequence. These instructions apply special rules that delete data not wanted and apply special formulas to the remaining data to reduce data volume while retaining the information content. Data are further encoded, using telecommunication techniques that allow error correcting of the data received at Earth; this process permits transmission of data at a lower signal strength.

Playing Back the Tape Recorder

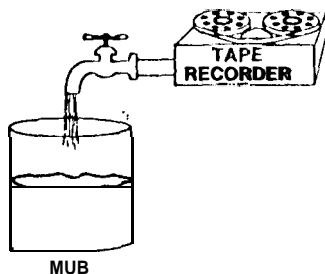
Playback of data from the tape recorder is scheduled anytime during the cruise phase of each orbit when the downlink is at least 8 bits per second. The autonomous playback process shines the available telemetry capability with real-time science (RTS) after the higher priority engineering data has been placed into the downlink. Unlike RTS, the playback process is dynamic and can respond to the daily variations in the downlink rate. The playback process is initiated, paused, resumed, or terminated through commands in the stored sequence.

The new software has improved the DMS tape recorder playback process. The innovative data compression methods performed onboard the orbiter allow retention of the most interesting and scientifically valuable information, while minimizing or eliminating less valuable data (such as the dark background of space) before transmission to Earth. Using a technique called "multi-framing," several images fill the dark region of space in the single frame that formerly carried one image. The CDS can now collect data from each of the modified science instruments by source (except SS1 data, compressed by AACs), edit each data stream, assemble the data into packets, assemble packets into virtual channel data units (VCDUs), and store those VCDUs in the multi-use buffer for later downlink. One sample of about 100 seconds of data acquired by the instrument is now equivalent to about 2/3 second of data on the tape!

Because many of the editing and selection algorithms are dependent on data type, it is not possible to predict exactly how much time or tape space will be used up in each tape reading session or "gulp." The CDS will continue to capture selected data from the tape until the quantity of data in the multi-use buffer exceeds an established CDS operating parameter called the "high water mark." At this time the data are sent to the playback processors along with their defined editing parameters. The tape motion will begin again when the processed data packets have been sent to the telemetry frame builder and the multi-use buffer level drops below the "low water mark." Upon that condition, the CDS will begin a new gulp process, incrementing data processing windows as needed when new data types are encountered on the tape recorder. Remember, all this happens without calling home!

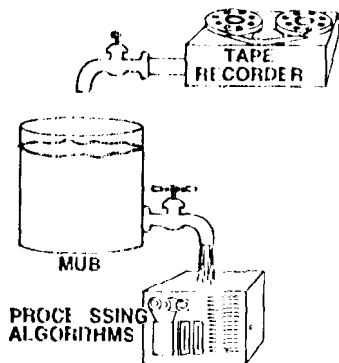
In what order is the data returned? Generally, in the order it was acquired, but spread over the several weeks of the orbital cruise. So data recorded in the first day or so of the encounter will be played back in the first week or so of cruise, and data recorded on the last day of the encounter will be played back in the last week or so of cruise. An interesting but also complicating characteristic of Galileo's playback process is that the achieved compression is not deterministic--probably not predictable to within better than days as to exactly when a given data set will be returned,

The following figures tell the story of the pipeline from Galileo to Earth. In the figure on the top, the playback process begins with both the DMS (tape recorder) and real-time science flowing data into MUB until the level hits the high water mark (HWM). The middle figure shows us that when the MUB is filled, the CDS starts processing the data by means of algorithms. The bottom figure illustrates the processed data, now chunked into packets, flowing down the pipeline.

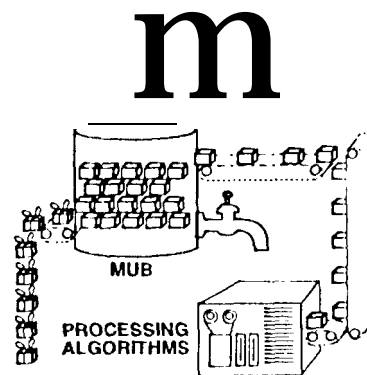


PLAYBACK PROCESS BEGINS WITH TAPE RECORDER POURING DATA INTO MUB UNTIL IT'S FULL

Filling the Downlink Efficiently



WITH THE MUB FULL, THE CDS STARTS PROCESSING THE DATA, SHOWING OUT UNNEEDED DATA AND COMPRESSING THE REMAINDER



TO DOWN LINK

PROCESSED PACKAGES GO BACK TO MUB, WHERE THEY WAIT TO BE DOWNLOADED

The Trip Detailed

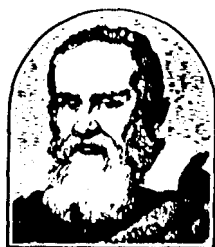
Where and when will events take place? Project Galileo has prepared Quick-Look Orbit Facts sheets to help you track our itinerary.

The time of arrival, the altitude and position at the time of closest approach, and the science highlights are just a few of the facts you'll have handy for each orbit. Maps of the encounter trajectory and the flyby geometry for each encounter offer some visual relief and point the way. A timeline summarizing the major tour events and the set of Quick-Look Orbit Facts can be found in the Appendix; they complete our description of the Galileo tour.

A Unique Experience

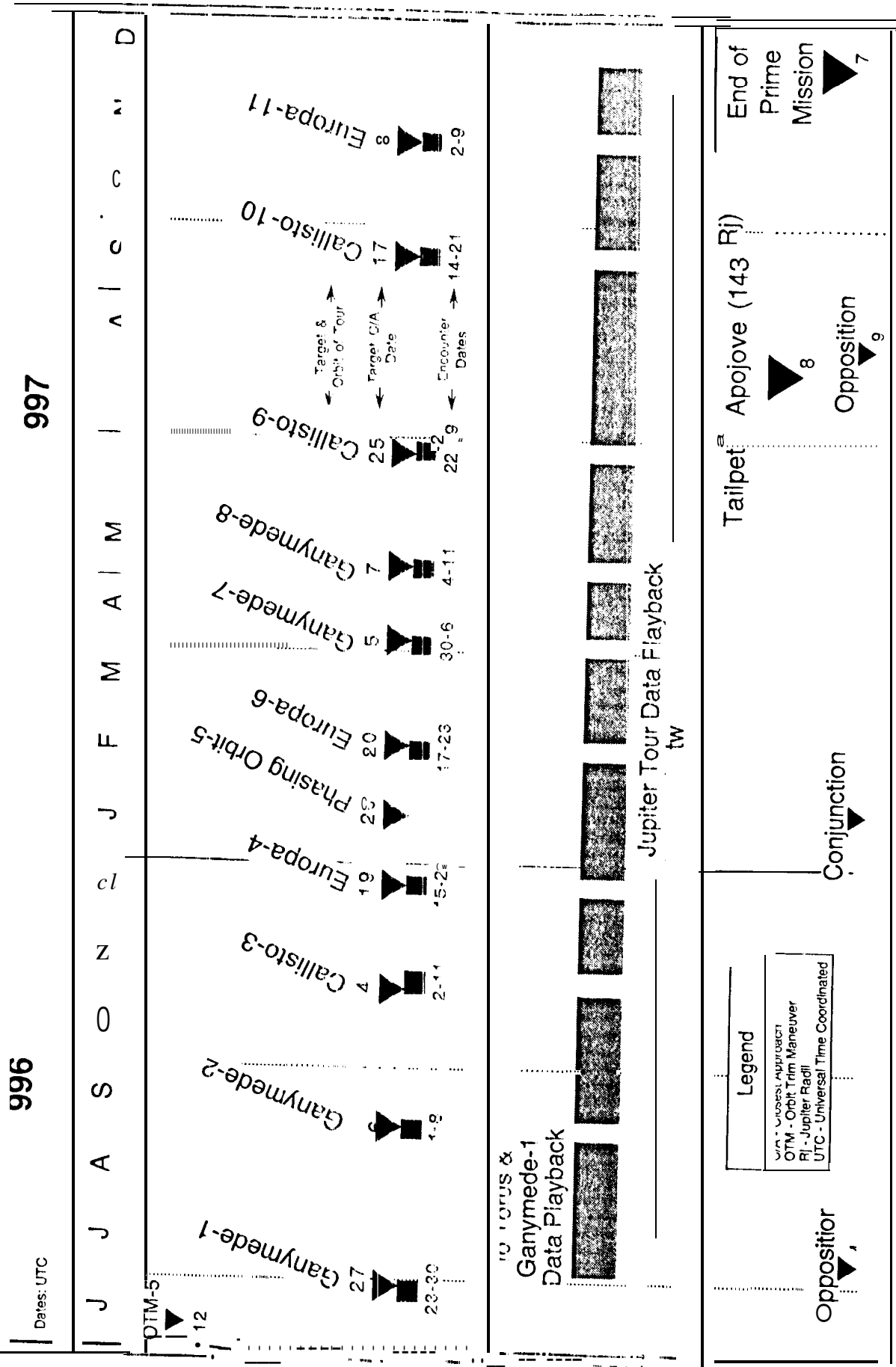
Though our tour will be ending in December 1997, the work of the scientists will be in full swing. They will be piecing together the observations and analyzing this valuable data for years to come. No doubt new understandings of our solar system will emerge from this first time visit by a spacecraft that orbited an outer planet. We look forward to unlocking the mysteries Jupiter holds.

APPENDIX

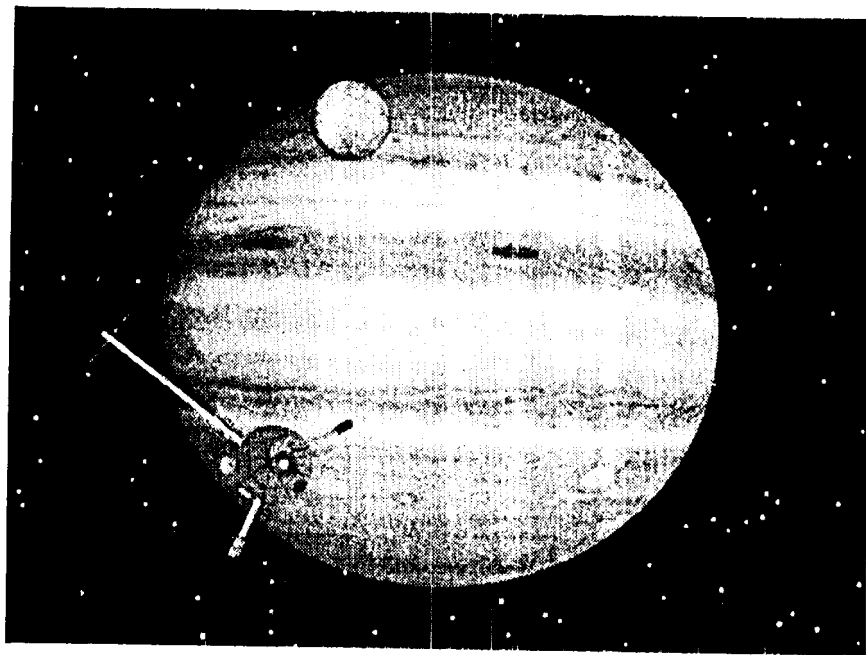


This appendix contains a timeline, Galileo Mission Overview (June 1996–December 1997), and a set of Quick-Look Orbit Facts sheets. The essentials of each orbit are listed. We have provided them as a handy reference while the orbiter's tour progresses in the months to come.

Galileo Mission Overview (June 1996 - Dec 1997)

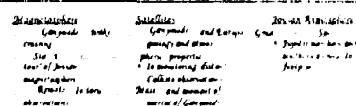
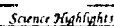
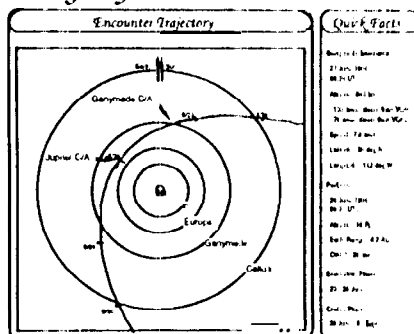
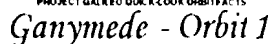


Project Galileo Quick-Look Orbit Fact Sheets

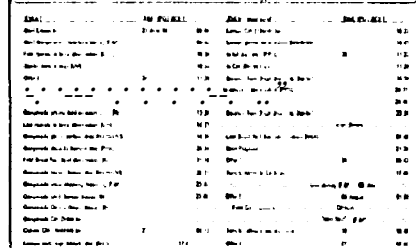
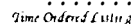
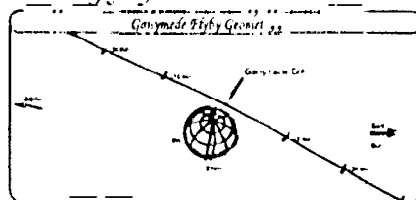
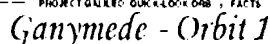


Fact Sheet Guide

Sections



References



Page 24

Title

Indicates the target satellite and the number of the orbit in the satellite tour. In this example, Ganymede is the target satellite on the first orbit of the orbital tour.

Encounter Trajectory

This plot shows the path of the spacecraft as it flies through the Jupiter system. The target satellite and Jupiter closest approaches are labeled and indicated by the white circles. The directions to the Sun and the Earth are indicated by the arrows near the top of the plot. These particular plots are also known as **North Trajectory Pole View plots**.

Science Highlights

This section provides a high level ~~non-~~**comprehensive** listing of the science that will be accomplished during this encounter period. The listing is divided amongst the three main ~~areas~~ of science interest: Jovian magnetosphere, satellites (**Galileo**, minor, Jupiter rings), and Jovian atmosphere.

Version Number and Publication Date

Quick Facts

This section provides a summary listing of the characteristics of the target satellite encounter as well as the Jupiter encounter, including a comparison of the target satellite flyby altitude to those of the Voyager spacecraft. It also defines the orbit encounter and cruise dates.

Satellite Flyby Geometry

This plot shows the path of the spacecraft as it encounters the target satellite. The target satellite closest approach is labeled and indicated by the white circles. The directions to the Sun, Earth and Jupiter are indicated by arrows on the plot. The grid on the satellite provides information about the flyby latitude and longitude. These plots are a combination of North and South Trajectory Pole View plots.

Time Ordered Listing

This section provides a listing of important mission and engineering events, as well as selected science observations that support the science mentioned in the Science Highlights section.

Fact Sheet Guide

Acronyms

AU - astronomical units	N - North	Rj - Jupiter radii
C/A - closest approach	NIMS - Near-Infrared Mapping Spectrometer	RS - Radio Science
deg - degrees	obs - observation	SCE1 - spacecraft event time
EUV - Extreme Ultraviolet Spectrometer	OTM - orbit trim maneuver	SS1 - Solid State Imaging
F&P - Fields and Particles instruments	OWLT - one way light time	UTC - Universal Time Coordinated
km - kilometers	PDT - Pacific Daylight Time	UVS - Ultraviolet Spectrometer
km/s - kilometers per second	FIST - Pacific Standard Time	VGR1 - Voyager 1
min - minutes	PPR - Photopolarimeter Radiometer	VGR2 - Voyager 2
		W - West

Glossary of Selected Terms

Alfvén wing - collection of electromagnetic waves generated as the presence of plasma leads to the "slowing down" of the magnetic field lines being swept past a satellite.

aurora - a glow in a planet's ionosphere produced by the interaction of the planet's magnetosphere with charged particles from the Sun.

Fields and Particles Instruments - compliment of instruments designed to provide data need to shed light on the structure and dynamical variations of the Jovian magnetosphere. This compliment is made up of the Dust Detector, Energetic Particles Dectector, Heavy Ion Counter, Magnetometer, plasma and Plasma Wave Subsystems.

magnetosphere - the region of space in which a planet's magnetic field dominates that of the solar wind.

magnetotail - the portion of a planetary magnetosphere pulled downstream by the solar wind.

occultation - period of time during which sunlight or the radio signals to/from a spacecraft are interrupted by the intervention of a celestial body.

OPNAV - SSI image taken to support optical navigation; image typically consists of the limb of one main body (Jupiter or a satellite) and three to four stars.

palimpsest - a roughly circular spot on icy satellites, thought to identify a former impact crater.

phase angle - the angle between the Sun, an object, and an observer. 0 degrees phase means the Sun is behind the observer.

plasma - a highly ionized gas, consisting of almost equal numbers of free electrons and positive ions.

plasma sheet - low energy plasma, largely concentrated within a few planetary radii of the equatorial plane, distributed throughout the magnetosphere throughout which concentrated electric currents flow.

satellites, Galilean - Io, Europa, Ganymede, and Callisto; four largest satellites of Jupiter discovered by Galileo in 1610.

satellite wake - region created in front of the Galilean satellites as the charged particles that corotate with the Jovian magnetosphere sweep past the satellites.

solar conjunction - period of time during which the Sun is in or near the spacecraft-Earth communications path, thus corrupting the communications signals.

torus, 10- ring-like cloud of neutral and ionized gases (plasma) along Io's orbit believed to be associated with the volcanic eruptions on Io.

External Sources:

Dessler, J. *Physics of the Jovian Magnetosphere*. Cambridge University Press, 1983.

Yates, C. M., et. al. *Galileo: Exploration of Jupiter's System*. NASA, 1985

Kelly Beatty, J. and A. Chaikin. *The New Solar System*. 3rd edition. Cambridge University Press, 1990.

Space Science Reviews. Volume 60. Kluwer Academic Publishers, 1992.

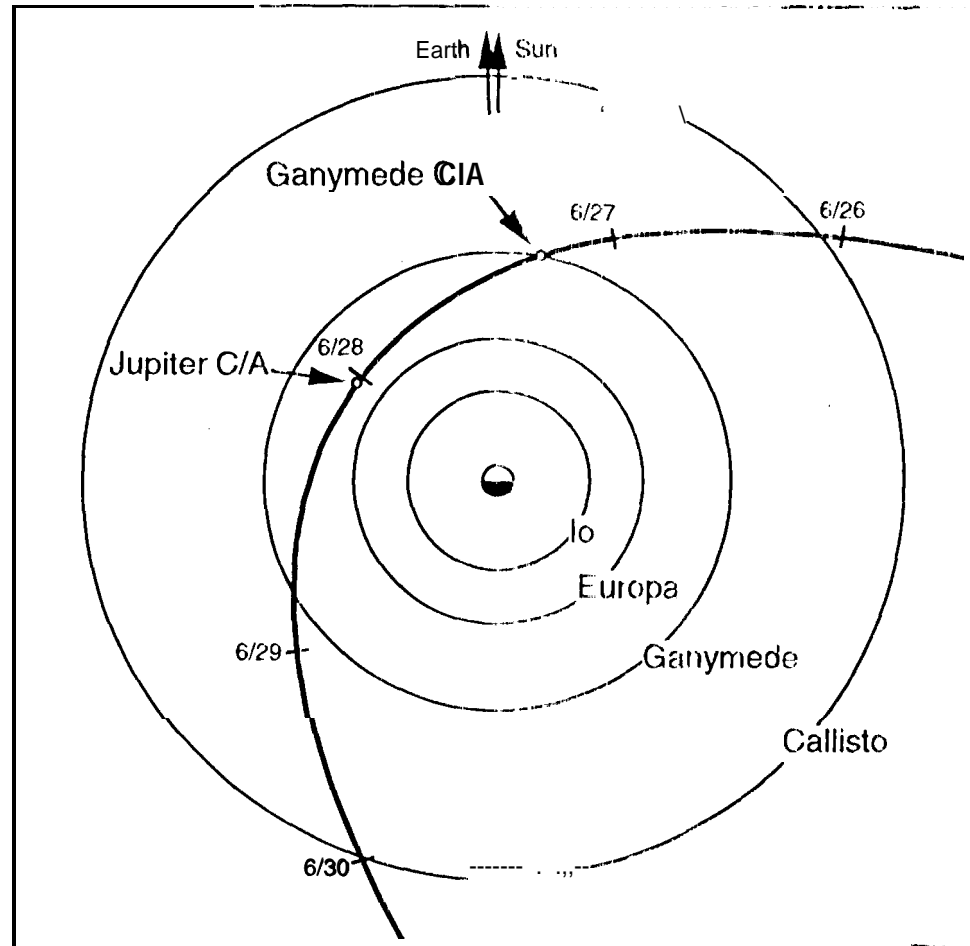
Disclaimers / Additional Resources

Disclaimer: The information contained in these fact sheets is based on the latest available mission plans as of the publication date. Mission plans are subject to change as they go through the final planning cycle prior to transmission to the spacecraft. Stay tuned for information updates.

For additional information contact us at: Galileo Outreach Coordination, Jet Propulsion Laboratory, M/S 264-765, 4800 Oak Grove Drive, Pasadena, CA 91109-8099. Phone: (818) 393-0592, Fax: (818) 393-4530, Email: askgalileo@gllsvc.jpl.nasa.gov. Or visit our home page at <http://www.jpl.nasa.gov/galileo>.

Ganymede - Orbit 1

Encounter Trajectory



Quick Facts

Ganymede Encounter

27 June 1996

06:29 UTC

Altitude: 844 km

133 times closer than VGR1

70 times closer than VGR2

Speed: 7.8 km/s

Latitude: 30 deg N

Longitude: 112 deg W

Perijove

28 June 1996

00:31 UTC

Altitude: 10 R_J

Earth Range: 4.2 AU

OWLT: 35 min

Encounter Phase

23-30 June

Cruise Phase

30 June -01 Sept

Science Highlights

Magnetosphere

- Ganymede wake crossing.
- Start of first "mini-tour" of Jovian magnetosphere
- Remote Io torus observations

Satellites

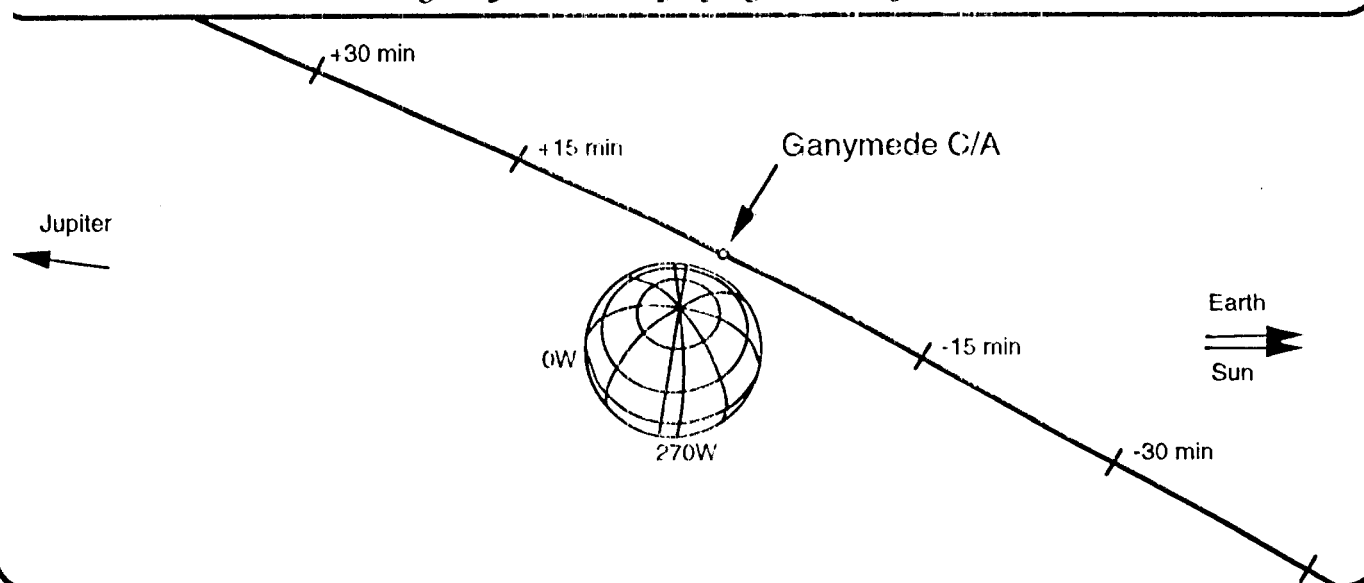
- Ganymede and Europa geology and atmospheric properties
- Io monitoring, distant Callisto observations
- Mass properties of Ganymede

Jovian Atmosphere

- Great Red Spot
- Jupiter northern and southern aurora, Io footprint

Ganymede -- Orbit 1

Ganymede Flyby Geometry



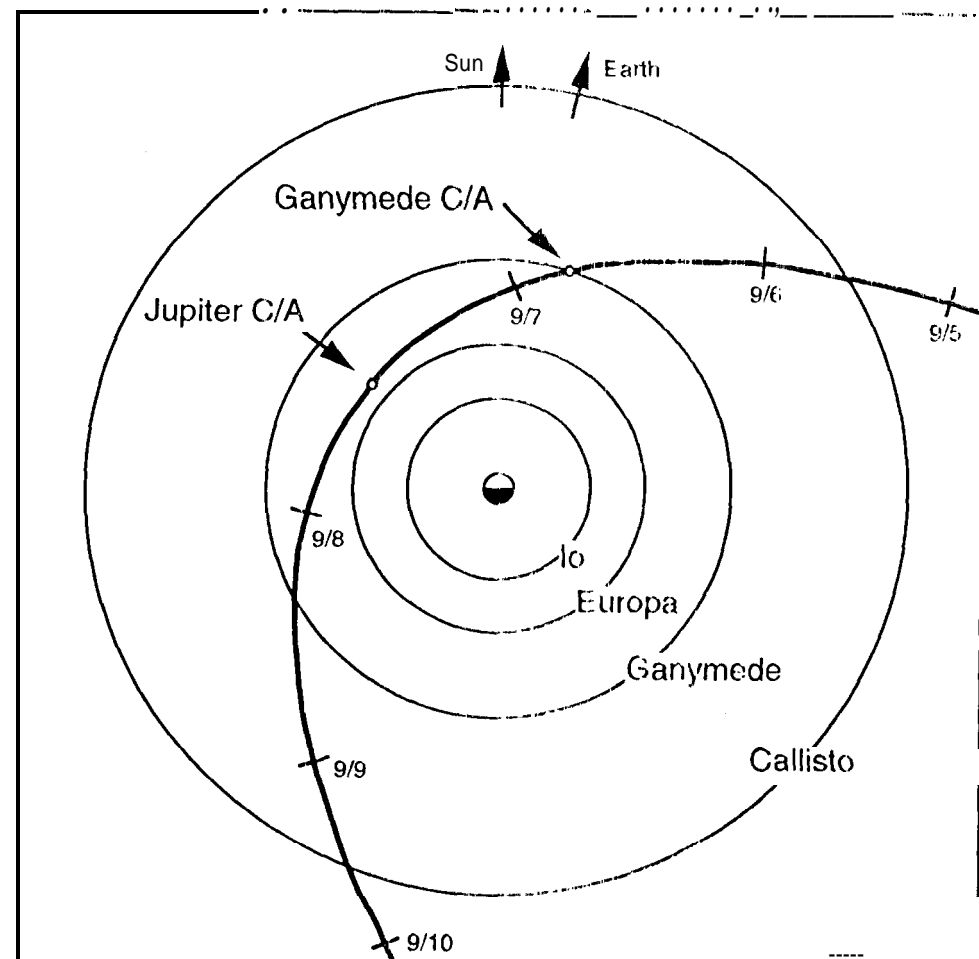
Time

Ordered Listing

EVENT	TIME (PDT-SCET)	EVENT (continued)	TIME (PDT-SCET)
Start Encounter	23 June 96 09:00	Europa C/A (156000 km)	18:22
Start Ganymede-1 real-time survey (F&P)	09:02	Europa global observation (NIMS/SSI)	18:43
First remote 10 torus observation (EUV)	10:20	10 full disk map (PPR) 28	11:22
Jupiter auroral map (UVS)	19:54	10 C/A (697000 km)	11:28
OTM-6 24	11:30	Science 1 urn (High phase Io, Jupiter)	15:30
First 10 monitoring observation (SS1) 25	10:36	10 eclipse observation (PPR)	20:37
Ganymede global color image (SSI) 26	01:45	10 eclipse observation (SS1)	20:46
Ganymede gravity field measurement (RS)	13:29	Science 1 urn (High phase Io, Jupiter)	23:38
Last remote 10 torus observation (UVS)	14:23	Last 10 monitoring observation (NIMS) 29	04:32
Ganymede global surface map (NIMS/UVS)	14:30	Last Great Red Spot observation (NIMS)	07:45
Ganymede dayside thermal map (PPR)	20:24	Start Playback	21:30
First Great Red Spot observation (SS1)	21:18	OTM-7 30	00:42
Ganymede Nippur Sulcus obs. (NIMS/UVS)	22:21	1 urn to return to Earth point	17:45
Ganymede wake crossing recording (F&P)	23:07	End Ganymede-1 real-time survey (F&P) 02 July	17:00
Ganymede Uruk Sulcus mosaic (SS1)	23:08	OTM-8 05 August	01:00
Ganymede Galileo Regio mosaic (SS1)	23:09	First Ganymede-2 approach OPNAV 09	18:49
Ganymede C/A (3480 km)	23:29	Start 1st magnetosphere 'mini-tour' (F&P) 14	17:00
Callisto C/A (1040000 km) 27	06:13	Turn for attitude maintenance 18	18:40
Europa north high latitude obs. (NIMS)	17:01	OTM-9 27	10:30
Jupiter C/A (789000 km)	17:31	End Playback 01 September	09:00

Ganymede - Orbit 2

Encounter Trajectory



Quick Facts

Ganymede Encounter

06 September 1996
19:00 UTC

Altitude: 250 km

448 times closer than VGR1

238 times closer than VGR2

Speed: 8.0 km/s

Latitude: 80 deg N

Longitude: 123 deg W

Perijove

07 September 1996
13:37 UTC

Altitude: 9.7 R_J

Earth Range: 4.7 AU

OWLT: 39 min

Encounter Phase

01-08 September

Cruise Phase

08 Sept -02 Nov

Science Highlights

Magnetosphere

- Ganymede north Alfvén wing crossing
- Central orbit in first "mini-tour" of Jovian magnetosphere

Satellites

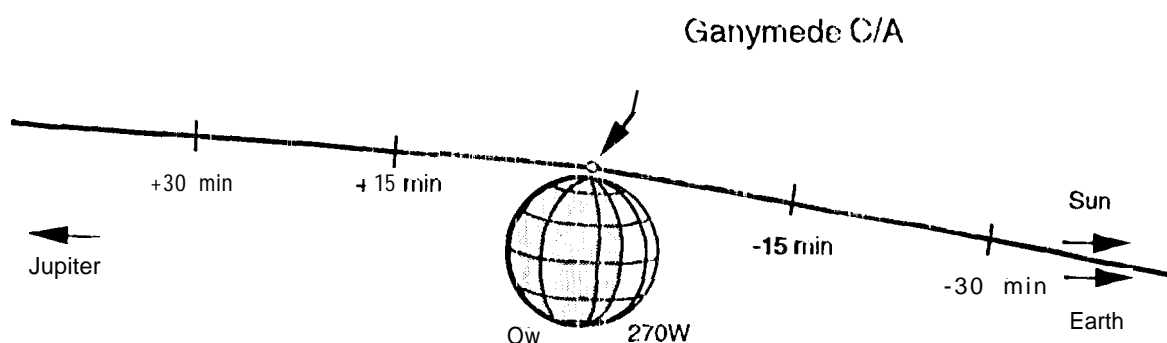
- Unique Ganymede north polar pass
- Europa low phase global images
- Callisto, Io monitoring, Amalthea

Jovian Atmosphere

- Stratospheric Circulation
- Jupiter southern aurora
- Shoemaker-Levy 9 remnant material images

Ganymede - Orbit 2

Ganymede Flyby Geometry

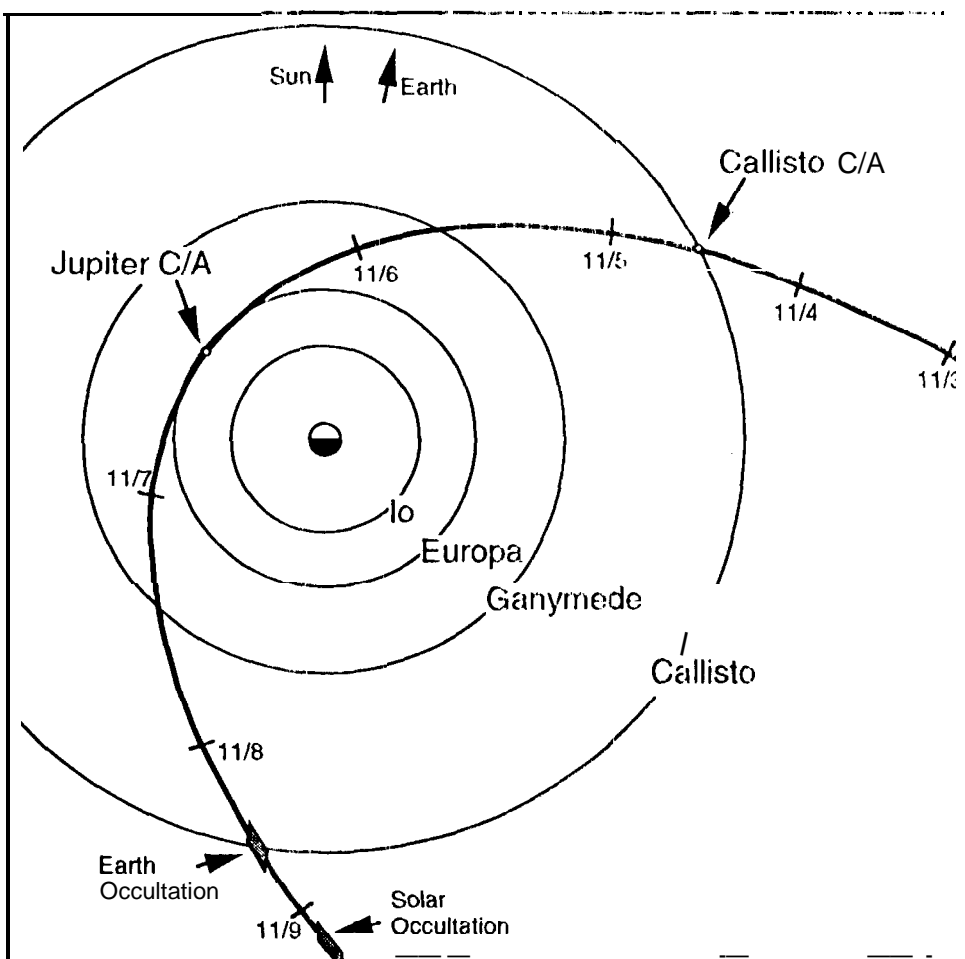


Time Ordered Listing

EVENT	TIME (PDT/PST-SCET)	EVENT (continued)	TIME (PDT/PST-SCET)
Start Encounter	01 September 1996 09:00	Jupiter C/A (762000 km)	06:37
First 10 monitoring observation (SS1)	02 16:14	Europa low phase photometry (SS1)	07:39
Last Ganymede-2 approach OPNAV	22:35	Europa C/A (673000 km)	10:06
Shoemaker-Levy 9 impact zone obs. (SS1) 03	10:10	Europa main circular feature (NIMS)	10:07
Shoemaker-Levy 9 impact zone obs. (NIMS)	10:25	Europa polarimetry (PPR)	14:50
Jupiter auroral map (UVS)	16:48	Last 10 monitoring observation (NIMS)	22:21
OTM-10	04 11:50	Callisto low phase photometry (SS1)	08 06:25
Ganymede gravity field measurement (RS) 06	0201	Start Playback	09:00
Ganymede north pole map (NIMS/UVS)	11:08	Callisto polarimetry (PPR)	16:31
Ganymede wake and wing recording (F&P)	11:31	Callisto C/A (424000 km)	09 03:24
Ganymede Anshar Sulcus (SS1)	11:33	Callisto global coverage (NIMS)	03:25
Ganymede palimpsest (SS1)	11:41	OTM-11	14:30
Ganymede C/A (2880 km)	12:00	1 urn for attitude maintenance	23 10:00
Science Turn (Jupiter stratospheric map)	13:07	OTM-12	08 October 07:00
Jupiter stratospheric circulation map (UVS)	14:12	First Callisto-3 approach OPNAV	09 07:38
Turn to return to Earth point	16:41	Last Callisto-3 approach OPNAV	30 15:23*
10 full disk map (PPR)	21:56	OTM-13	01 November 05:30
10 C/A (441000 km)	2225	End Playback	02 08:00
Amalthea full disk imaging (SS1) 07	01:14	* denotes transition from PDT to PST,	

Callisto -- orbit.?

Encounter Trajectory



Quick Facts

Callisto Encounter

04 November 1996
13:30 UTC

Altitude: 1104 km

112 times closer than VGR1
192 times closer than VGR2

Speed: 8.0 km/s

Latitude: 13 deg N

Longitude: 78 deg W

Perijove

06 November 1996
13:27 UTC

Altitude: 8.2 R_J

Earth Range: 5.6 AU

OWLT: 46 min

Encounter Phase

02-11 November

Cruise Phase

11 Nov - 15 Dec

Science Highlights

Magnetosphere

- Completion of first "mini-tour" of Jovian magnetosphere
- Callisto wake and Alfven wing crossings

Satellites

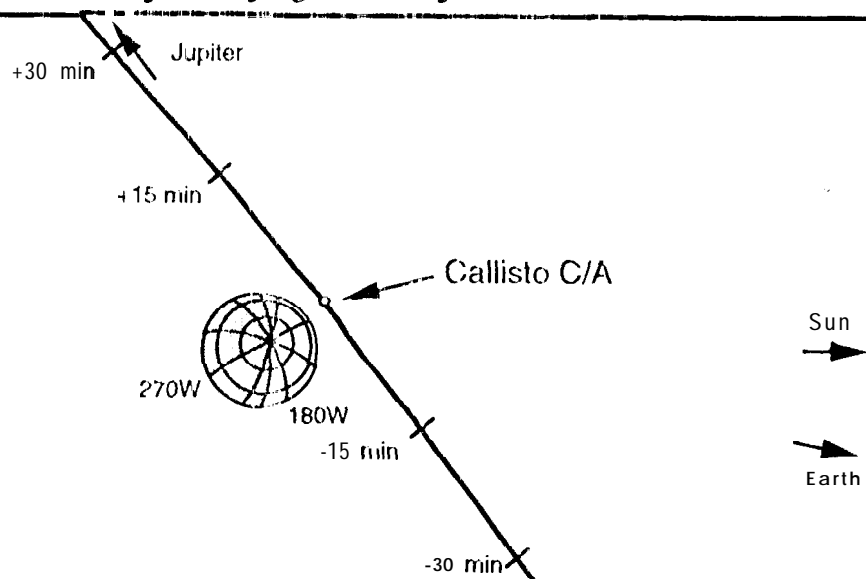
- Callisto Asgard Basin
- Europa non-targeted encounter - volcanism obs.
- Closest Io approach of Tour
- Mass properties of Callisto

Jovian Atmosphere

- White oval observations
- Jupiter northern aurora
- Jupiter atmosphere during Solar occultation

Callisto - Orbit. ?

Callisto Flyby Geometry

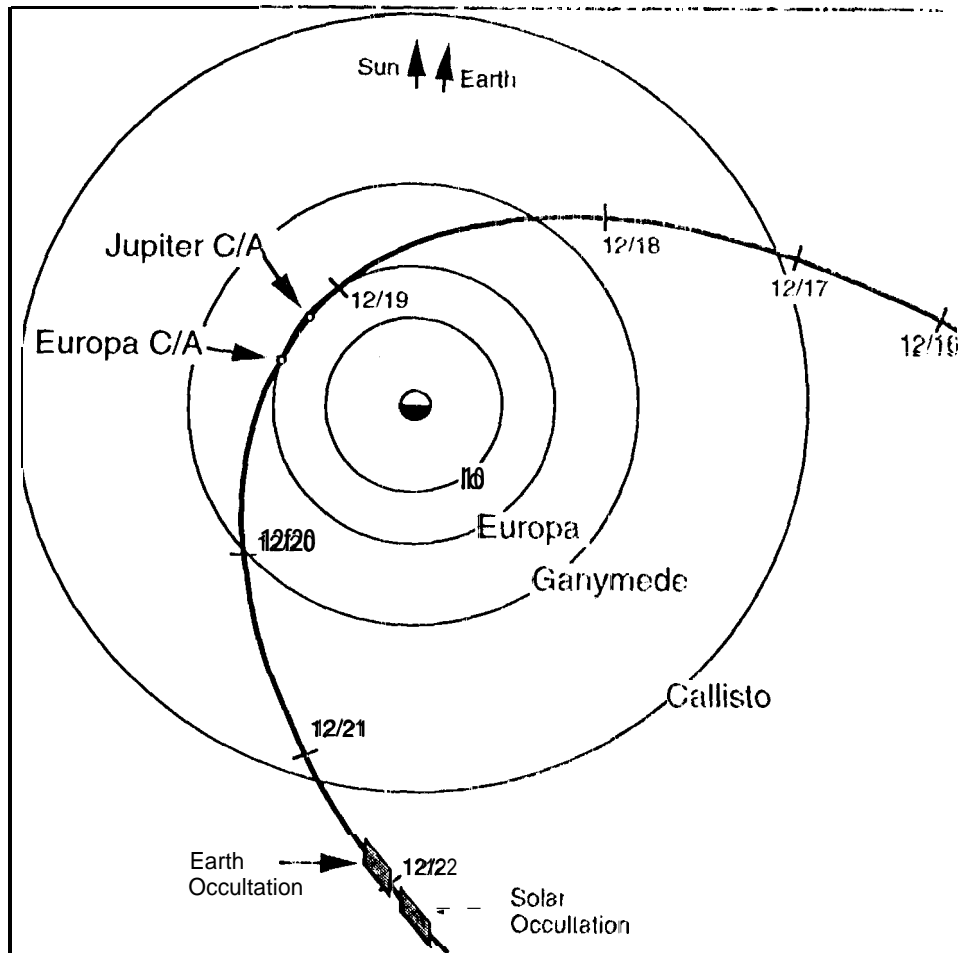


Time Ordered Listing

EVENT	TIME (PST-SCET)	EVENT (continued)	TIME (PST-SCET)
Start Encounter	02 November 1996 08:00	Last "White oval" observation (NIMS) 07	09:40
First Jupiter aurora observation (UVS)	18:14	Turn to return to Earth point	12:30
Callisto Asgard Basin observation (SSI) 03	11:44	Start Earth occultation by Jupiter 08	02:36
Gravity field measurement - Callisto (RS)	1930	End Earth occultation by Jupiter	09:15
Callisto wake crossing recording (F&P) 04	05:11	Science 1 urn (Solar occultation)	15:00
Callisto C/A (3510 km)	05:30	Start Solar occultation by Jupiter	18:18
Callisto Valhalla region observation (SSI)	05:35	First Solar occultation observation (UVS)	18:35
Callisto dark map observation (PPR)	06:18	Last Jupiter aurora observation (SSI)	21:18
First "White oval" observation (NIMS)	18:14	Turn to return to Earth point 09	02:00
First Io monitoring observation (NIMS) 05	20:00	End Solar occultation by Jupiter	02:15
10 Topographical map (SS1)	22:07	Last Solar occultation observation (UVS)	05:10
High spatial and spectral 10 obs, (NIMS) 06	03:49	OTM 14	23:00
10 C/A (244000 km)	04:05	Start Playback 10	18:00
Jupiter C/A (658000 km)	05:27	End 1st magnetosphere "mini-tour" (F&P) 11	12:00
Europa C/A (34000 km)	10:43	Turn for attitude maintenance	12:00
Europa dark map observation (PPR)	12:27	OTM-15 27	11:43
Europa limb occultation obs. (NIMS)	12:41	First Europa-4 approach OPNAV C2 December	01:01
Last Io monitoring observation (NIMS)	15:21	Start Europa-4 real-time survey (F&P) 13	13:00
Science Turn (High phase Jupiter)	18:50	Last Europa-4 approach OPNAV	09:21
Ganymede C/A (1050000 km)	20:49	End Playback 14	16:00

Europa -- Orbit 4

Encounter Trajectory



Quick Facts

Europa Encounter

19 December 1996
06:54 UTC

Altitude: 692 km

1058 times closer than VGR1
295 times closer than VGR2

Speed: 5.7 km/s

Latitude: 0 deg N

Longitude: 37 deg W

Perijove

19 December 1996
03:22 UTC

Altitude: 8.2 R_J

Earth Range: 6.0 AU

OWLT: 50 min

Encounter Phase

15-22 December

Cruise Phase

22 Dec 96-17 Feb 97

Science Highlights

Magnetosphere

- Europa wake and north Alfvén wing crossings
- North to south plasma sheet crossing

Satellites

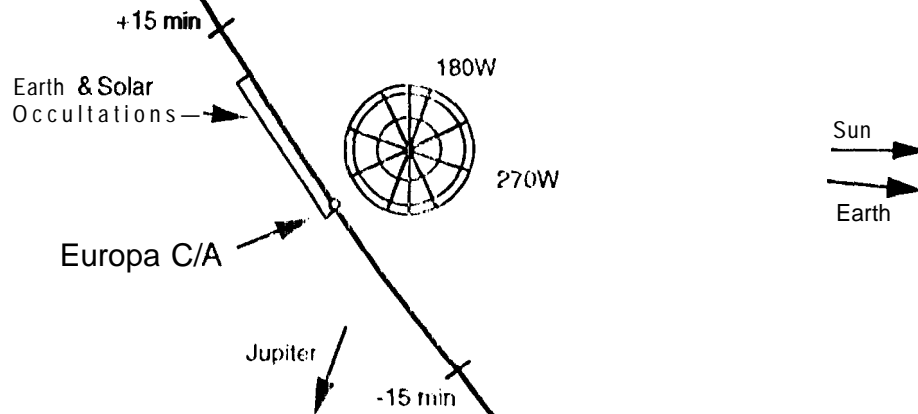
- Excellent Europa dayside and nightside coverage
- Io partial-eclipse
- Jupiter rings
- Amalthea, Thebe, Adrastea

Jovian Atmosphere

- Northern equatorial belt "hot spot" observations
- Atmospheric profile during Earth occultation
- Jupiter northern aurora

Europa Orbit 4

Europa Flyby Geometry

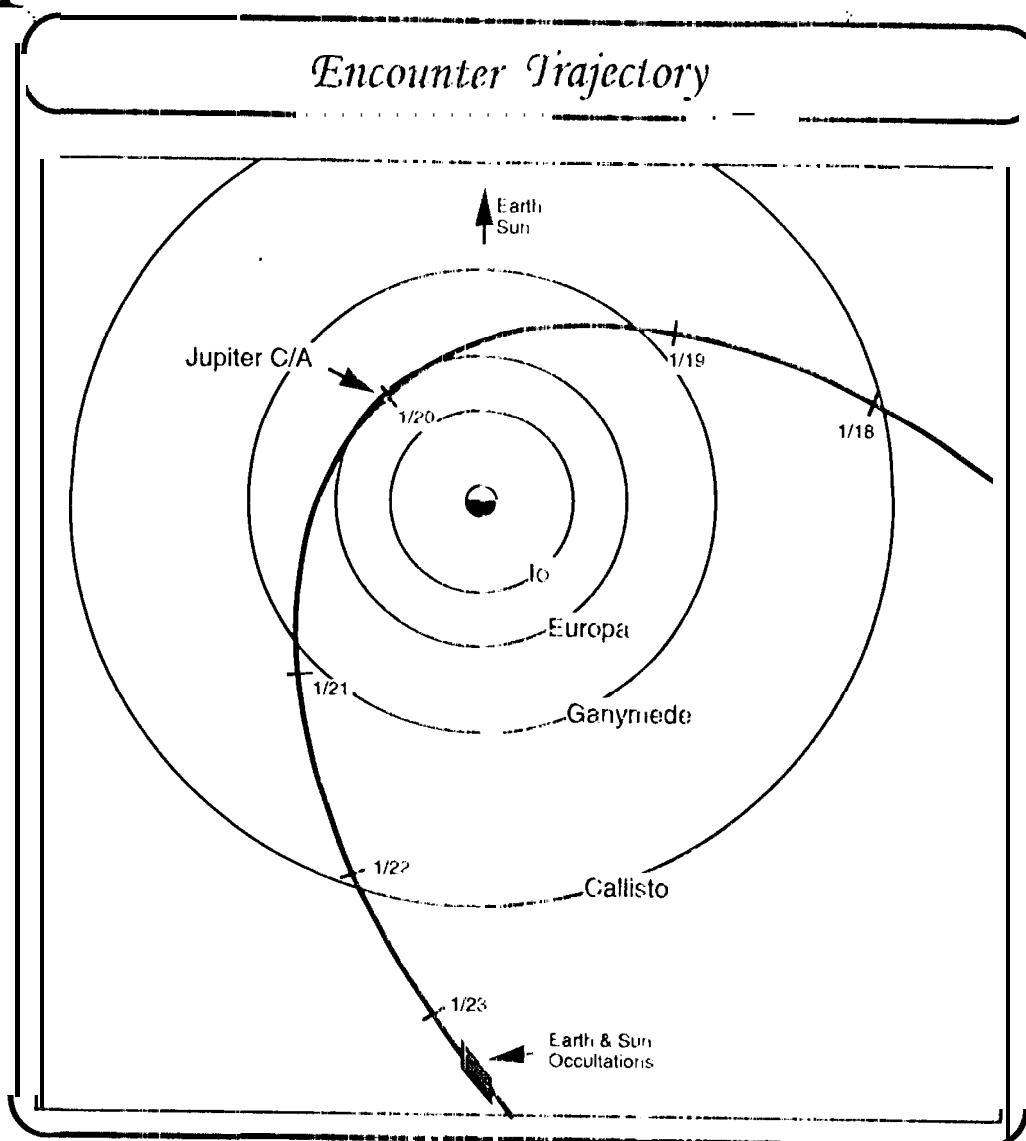


Time Ordered Listing

EVENT	TIME (PST-SCET) ----	EVENT (continued)	TIME (PST-SCET)
Start Encounter	14 December 1996 16:00	Turn to return to Earth point	10:50
OTM-16	15 18:30	Atmospheric profile during occultation (RS) 21	08:17
Jupiter auroral map (UVS)	16 02:00	Start Earth occultation by Jupiter	09:44
10 eclipse ingress observation (NIMS)	17 11:06	End Earth occultation by Jupiter	16:37
10 eclipse thermal observation (SSI)	11:45	Plasma sheet crossing recording (F&P)	17:20
10 eclipse egress observation (NIMS)	13:24	Start Solar occultation by Jupiter	19:00
First "Hot spot" observation (PPR)	19:20	End Solar occultation by Jupiter	22 02:44
Amalthea imaging (SSI)	23:09	Start Playback	03:00
Thebe imaging (SSI)	18 00:06	End Europa-4 real-time survey (F&P)	06:49
10 C/A (321000 km)	13:37	OTM-17	17:40
Europa global mosaic (NIMS)	17:17	"Turn for attitude maintenance"	26 12:00
Europa day/night thermal map (PPR)	17:54	OTM-18	04 January 1997 04:30
Jupiter C/A (655000 km)	19:22	"Turn for attitude maintenance"	08 06:15
Adrastea imaging (SSI)	19:26	Start Solar conjunction*	10 14:14
Europa global map (SSI)	19:35	End Solar conjunction	28 07:09
Europa Double Linea area (NIMS)	22:27	OTM-19	06 February 01:30
Europa wake crossing recording (F&P)	22:45	First Europa-6 approach OPNAV	20:45
Start Solar occultation by Europa	22:54	Turn for attitude maintenance	10 10:02
Start Earth occultation by Europa		1st Europa-6 approach OPNAV	15 21:35
Europa C/A (2260 km)		Start Europa-6 real-time survey (F&P)	01:00
End Solar occultation by Europa	23:05	End Playback	16 16:00
End Earth occultation by Europa	23:06		
Ganymede C/A (792000 km)	19 12:13		
Science Turn (High phase Jupiter)	19:05		
First high phase Jupiter observation (SSI)	22:53		
Callisto C/A (1490000 km)	20 05:33		
Last high phase Jupiter observation (SSI)	07:27		
Jupiter rings observations (NIMS)	08:06		
Last "Hot spot" observation (UVS)	10:06		

*Solar conjunction contains a phasing orbit fly through the Jovian system. Refer to Jupiter - Orbit 5 supplement.

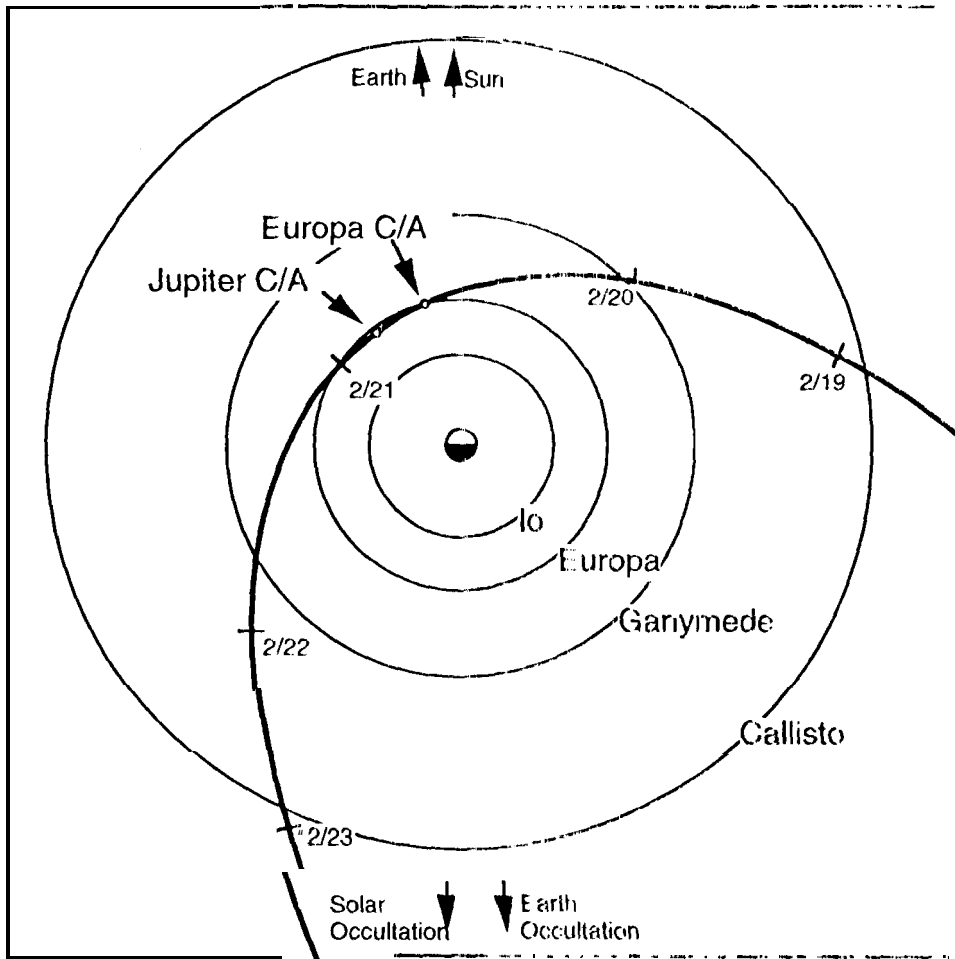
Jupiter - Orbit 5- Phasing



EVENT	TIME (PST-SCET)
Start Solar conjunction	10 January 1997 14:14
Ganymede C/A (1 150 000 km)	19 01:35
Jupiter C/A (6460(10 km)	16:28
Europa C/A (28900 km)	17:12
Callisto C/A (600 000 km)	21 12:18
Io C/A (1470 000 km)	17:25
Start Solar occultation by Jupiter	23 00:03
Start Earth occultation by Jupiter	01:54
End Solar occultation by Jupiter	08:51
End Earth occultation by Jupiter	10:32
End Solar conjunction	28 07:09

Europa - Orbit 6

Encounter Trajectory



Quick Facts

Europa Encounter

20 February 1997
17:03 UTC

Altitude: 587 km

1247 times closer than VGR
348 times closer than VGR2

Speed: 5.7 km/s

Latitude: 17 deg S

Longitude: 324 deg W

Perijove

20 February 1997
20:53 UTC

Altitude: 8,1 R_J

Earth Range: 6.0 AU

OWLT: 50 min

Encounter Phase

17-23 February

Cruise Phase

23 Feb -30 Mar

Science Highlights

Magnetosphere

- Europa south A lfvén wing crossing
- Jupiter magnetic equator crossing

Satellites

- Europa Argiope Linea and other fine-tuned regions
- Io plume monitoring
- Jupiter rings
- Thebe, Amalthea

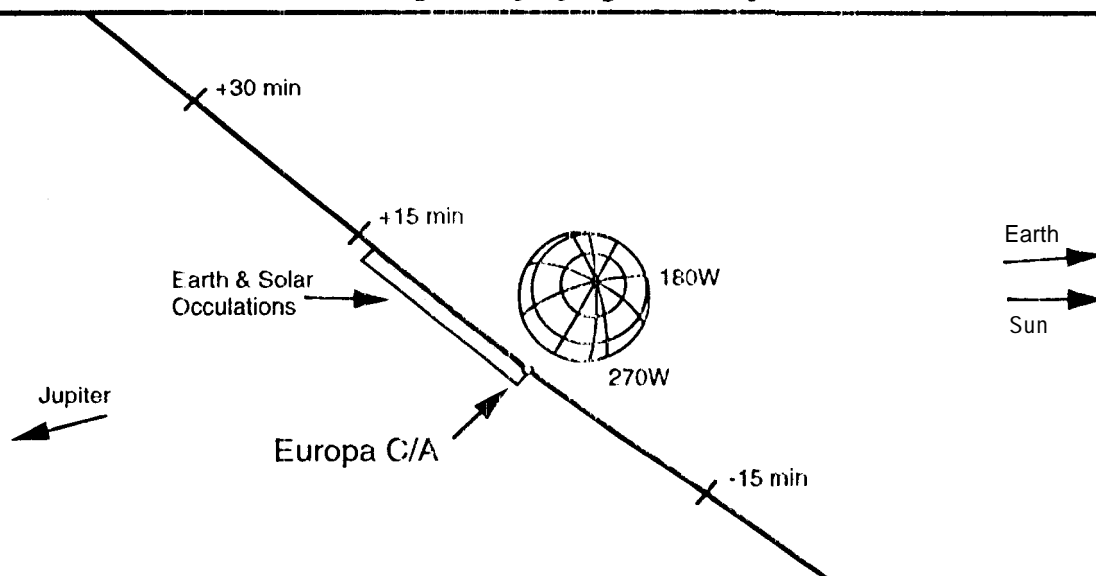
Jovian Atmosphere

- South equatorial belt - zone boundary
- Jupiter northern aurora

PROJECT GALILEO QUICK-LOOK ORBIT FACTS

Europa - Orbit 6

Europa Flyby Geometry

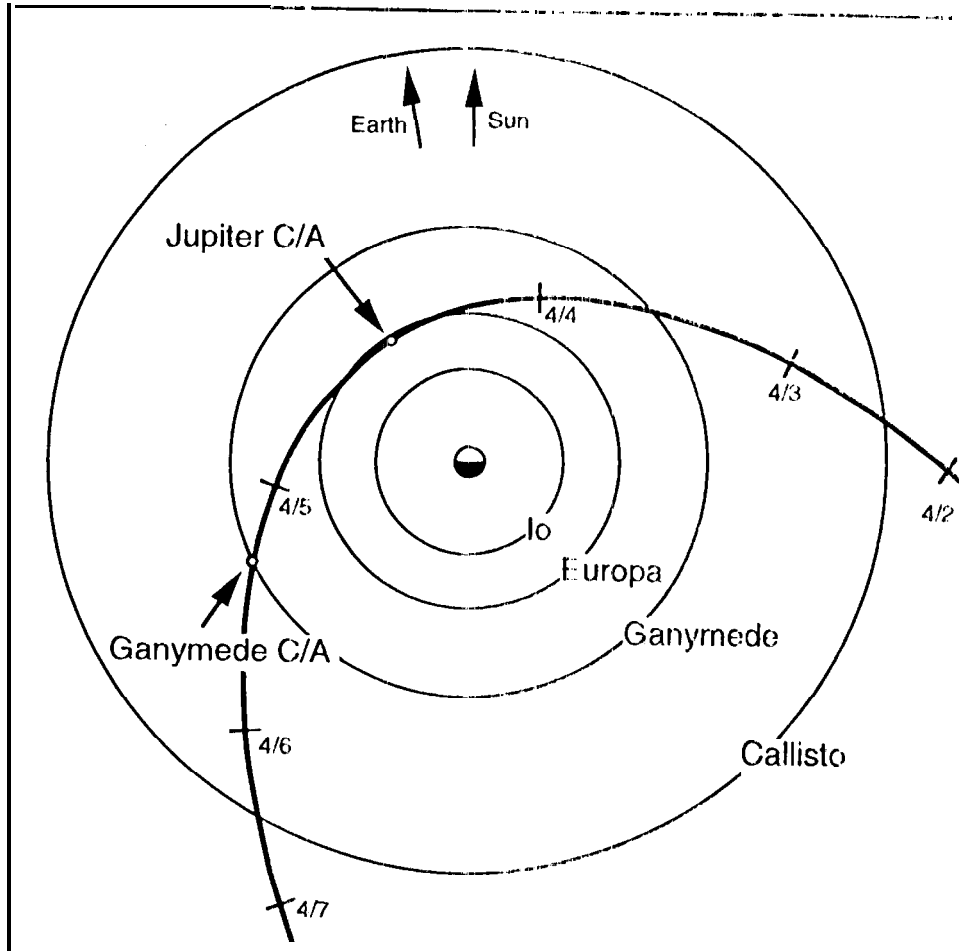


Time Ordered Listing

EVENT	TIME (PST-SCET)	EVENT (continued)	TIME (PST-SCET)
Start Encounter	16 February 1997 16:00	Europa global color map (SS1)	17:23
OTM-20	16:15	Last belt /zone observation (NIMS) 21	02:04
First 10 monitoring observation (SS1) 17	13:43	Last 10 monitoring observation (SS1)	02:56
Real-time Jupiter aurora obs. (UVS/EUV) 18	00:34	Ganymede C/A (318000 km)	08:26
Jupiter auroral map (UVS)	16:55	Callisto C/A (279000 km) 22	14:55
First belt /zone observation (SS1)	18:31	Start Playback	17:30
Thebe imaging (SS1) 19	15:01	OTM-21 23	20:00
Europa Terra Incognita obs. (NIMS) 20	04:03	Science 1 urn (Solar occultation) 25	03:47
10 C/A (401000 km)	11:04	Start Solar occultation by Jupiter	05:27
Europa Argiope Lines obs. (NIMS)	08:05	Jupiter rings observation (NIMS)	07:33
Europa Alfvén wing recording (F&P)	08:36	Turn to return to Earth point	16:44
Europa high resolution C/A obs. (PPR)	09:03	End Solar occultation by Jupiter	17:15
Start Earth occultation by Europa		End Europa-6 real-time survey (F&P)	19:00
Europa C/A (2150 km)		Start Earth occultation by Jupiter 26	11:13
Start Solar occultation by Europa	09:04	End Earth occultation by Jupiter 27	00:48
End Earth occultation by Europa	09:16	OTM-22 13 March	17:15
End Solar occultation by Europa	09:17	Turn for attitude maintenance 17	09:10
Jupiter C/A (652000 km)	12:53	Start Ganymede-7 real-time survey (F&P) 20	17:59
Jupiter magnetic equator recording (F&P)	13:06	First Ganymede-7 approach OPNAV 22	15:38
Amalthea imaging (SS1)	13:55	End Playback 30	08:00

Ganymede - Orbit 7

Encounter Trajectory



Quick Facts

Ganymede Encounter

05 April 1997
07:11 UTC

Altitude: 3059 km

37 times closer than VGR1

19 times closer than VGR2

Speed: 8.5 km/s

Latitude: 56 deg N

Longitude: 88 deg W

Perijove

04 April 1997
11:04 UTC

Altitude: 8.1 R_J

Earth Range: 5.5 AU

OWLT: 46 min

Encounter Phase

30 Mar -06 Apr

Cruise Phase

06 Apr -04 May

Science Highlights

J14aaneto.where

- Ganymede north Alfvén wing crossing
- First dawn side plasma sheet crossing

Satellites

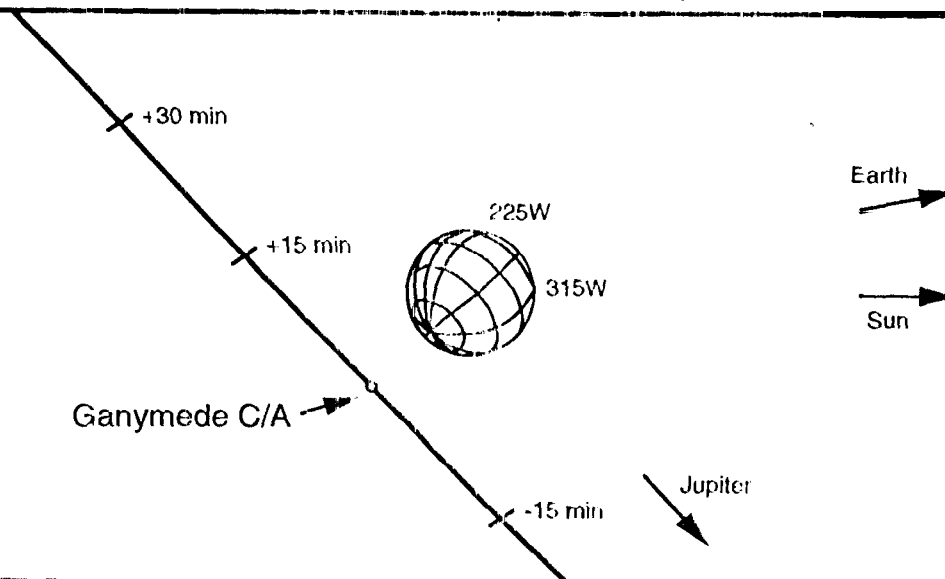
- Ganymede high energy impact regions (Kittu, etc.)
- Europa non-targeted encounter
- Callisto full color global mosaic

Jovian Atmosphere

- Visually clear or "Brown barge" regions
- Jupiter north-south aurora

Ganymede - Orbit 7

Ganymede Flyby Geometry



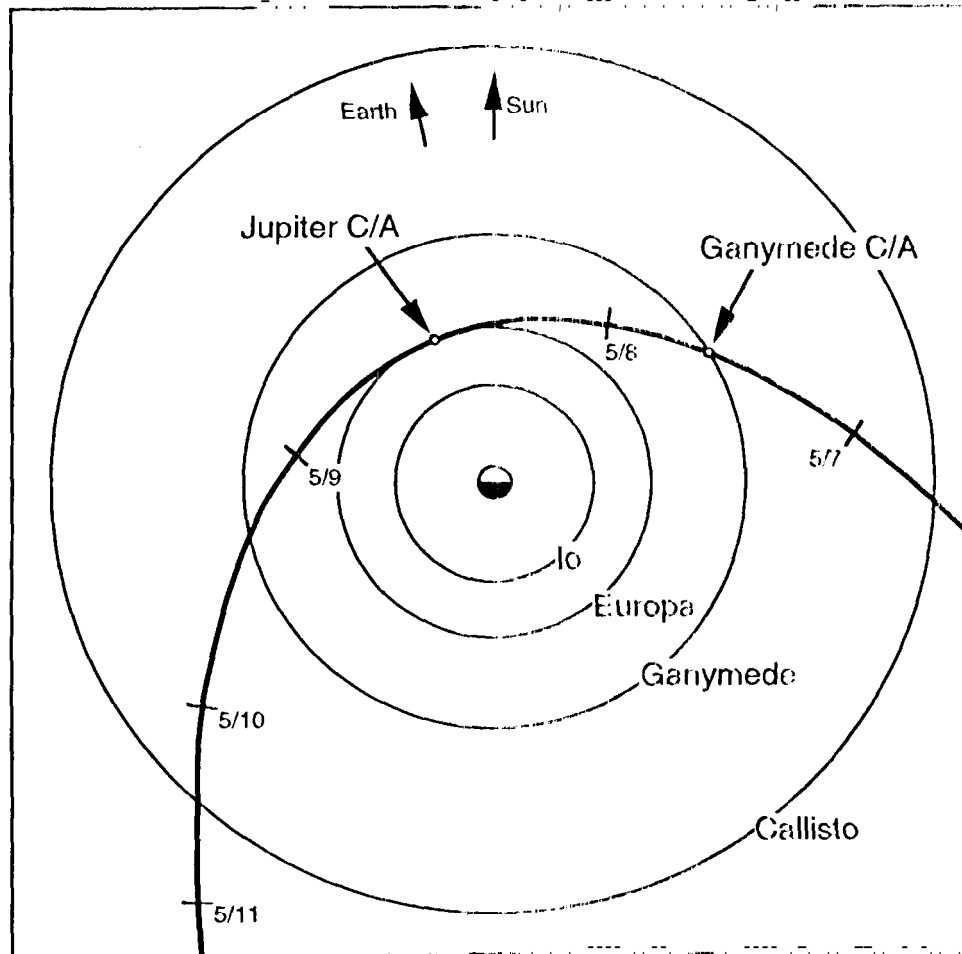
Time Ordered Listing

EVENT	TIME (PST/PDT)	EVENT	TIME (PST/PDT-SCET)		
Start Encounter	30 March 1997	08:00	Ganymede Kittu region (SS1)	22:40	
Dawn side plasma sheet recording (F&P)		10:50	Ganymede Alfvén wing recording (F&P)	22:56	
Last Ganymede-7 approach OPNAV	31	18:13	Ganymede polarimetry (PPR)	23:04	
OTM-23		20:40	Ganymede C/A (5690 km)	23:11	
Callisto polarimetry (PPR)	01 April	18:50	Ganymede global surface map (NIMS)	05	06:22
Real-time Jupiter aurora (UVS/EUV) 02		03:40	Last "Brown Barge" observation (NIMS)	06	08:56*
First "Brown Barge" observation (UVS)		07:30	Start Playback		09:00
Callisto global color image (SS1)		08:39	OTM-24	07	22:15
Jupiter auroral map (UVS)		08:50	End Ganymede-7 real-time survey (F&P)	14	13:00
Callisto C/A (636000 km)		08:52	Turn for attitude maintenance	18	11:00
Callisto global coverage (NIMS)		10:45	OTM-25	21	03:00
First 10 monitoring observation (NIMS)		21:15	First Ganymede-8 approach OPNAV	01 May	16:54
Europa full disk image (SS1)	03	09:44	Start Ganymede-8 real-time survey (F&P)	02	15:30
10 C/A (531000 km)		13:11	Last Ganymede-8 approach OPNAV		21:25
Europa dayside global thermal map (PPR)		18:32	End Playback	04	08:00
Europa Tyre Macula region (NIMS)		21:49			
Europa C/A (24600 km)		22:00	*denotes transition from PS1 to PDT.		
Jupiter C/A (652000 km)	04	03:04			
Last 10 monitoring observation (SS1)		16:15			
Ganymede Nicholson Regio (SS1)		22:29			

*denotes transition from PS1 to PDT.

Ganymede.Orbit 8

Encounter Trajectory



Quick Facts

Ganymede Encounter

07 May 1997
15:57 UTC

Altitude: 1585 km

71 times closer than VGR1
38 times closer than VGR2

Speed: 8.6 km/s

Latitude: 29 deg N

Longitude: 274 deg W

Perijove

08 May 1997
11:42 UTC

Altitude: 8.3 R_J

Earth Range: 5.0 AU

OWLT: 42 min

Encounter Phase

04-n May

Cruise Phase

11 May -22 June

Science Highlights

Magnetosphere

- Start of second "mini-tour" of Jovian magnetosphere
- Ganymede "upstream" wake crossing

Satellites

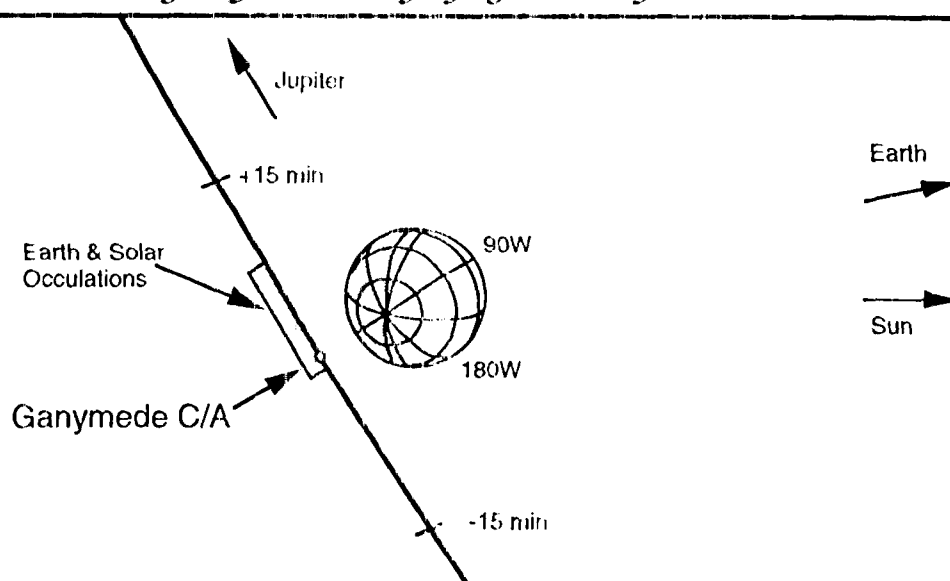
- Ganymede surface morphology: Osiris, Iliad, Sulcus, etc
- Callisto non-targeted encounter: South Pole
- Metis, Elara (UVS only)

Jovian Atmosphere

- South polar haze zone
- Jupiter northern and southern aurora, Io footprint

Ganymede - Orbit 8

Ganymede Flyby Geometry



Time Ordered Listing

EVENT	TIME (PDT-SCET) 1	EVENT (continued)	TIME (PDT-SCET)
Start Encounter	04 May 1997 09:00	End Earth occultation by Ganymede	09:03
OTM-26	09:30	End Solar occultation by Ganymede	09:05
Elara observing (UVS)	17:00	Turn to return to Earth point	12:04
Science Turn (to plume monitoring)	05 03:10	Last 10 monitoring observation, (NIMS)	15:58
First 10 monitoring observation (SS1)	06 02:33	Europa C/A (1290000 km)	08 02:49
Callisto south pole obs. (NIMS/UVS)	04:13	Jupiter C/A (663000 km)	04:42
Callisto south pole imaging (SS1)	05:08	Metis imaging (SS1)	09:34
Callisto C/A (35900 km)	05:11	Last south polar haze zone obs. (NIMS) 10	16:18
Callisto polarimetry / thermal obs. (PPR)	05:56	OTM 27	19:00
Jupiter auroral asymmetry map (UVS/NIMS)	16:37	Start Playback	11 09:00
Jupiter auroral variability map (UVS)	18:10	End Ganymede-8 real-time survey (F&P) 13	07:00
10 C/A (956000 km)	07 00:31	Start Earth occultation observing (RS) 24	22:04
First south polar haze zone obs. (UVS)	04:17	Start Earth occultation by Jupiter	25 02:36
Ganymede Oris observing (NIMS)	06:18	End Earth occultation by Jupiter	20:52
Ganymede dayside thermal obs. (PPR)	06:38	End Earth occultation observing (RS) 26	01:25
Ganymede Tiamat Sulcus (SSI)	07:35	Start 2nd in Magnetosphere "mini-tour" (F&P) 02 June	09:00
Ganymede C/A recording (F&P)	08:38	OTM-28	20:00
Start Earth occultation by Ganymede	08:56	First Callisto-9 approach OPNAV	17 22:30
Start Solar occultation by Ganymede	08:57	Last Callisto-9 approach OPNAV	20 18:45
Ganymede C/A (4120 km)		End Playback	22 09:00

Callisto - Orbit 9

Encounter Trajectory

Quick Facts

Callisto Encounter

25 June 1997
13:47 UTC

Altitude: 416 km

298 times closer than VGR1
511 times closer than VGR2

Speed: 8.2 km/s

Latitude: 2 deg N

Longitude: 259 deg W

Perijove

27 June 1997
11:52 UTC

Altitude: 9.8 R_J

Earth Range: 4.3 AU

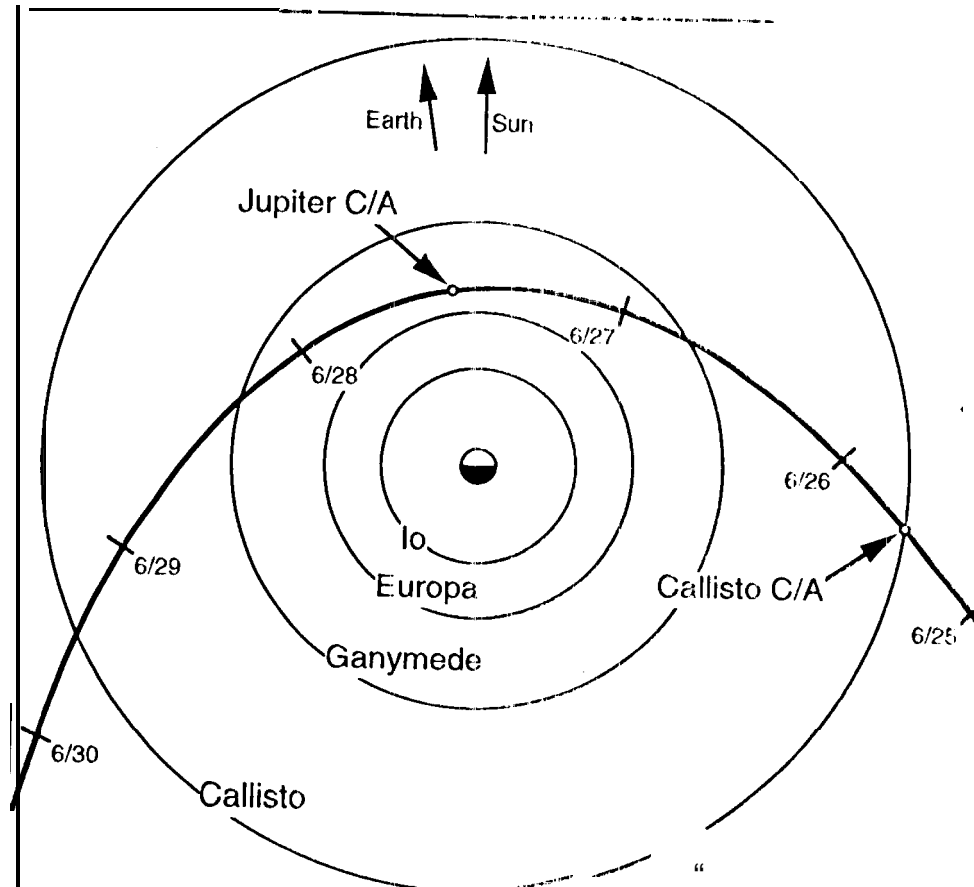
OWLT: 36 min

Encounter Phase'

22-29 June

Cruise Phase

29 June -14 Sept



Science Highlights

Magnetosphere

- Unique deep magnetotail passage (143 R_J - during cruise phase).
- Central orbit in second "mini-tour" of Jovian magnetosphere

Satellites

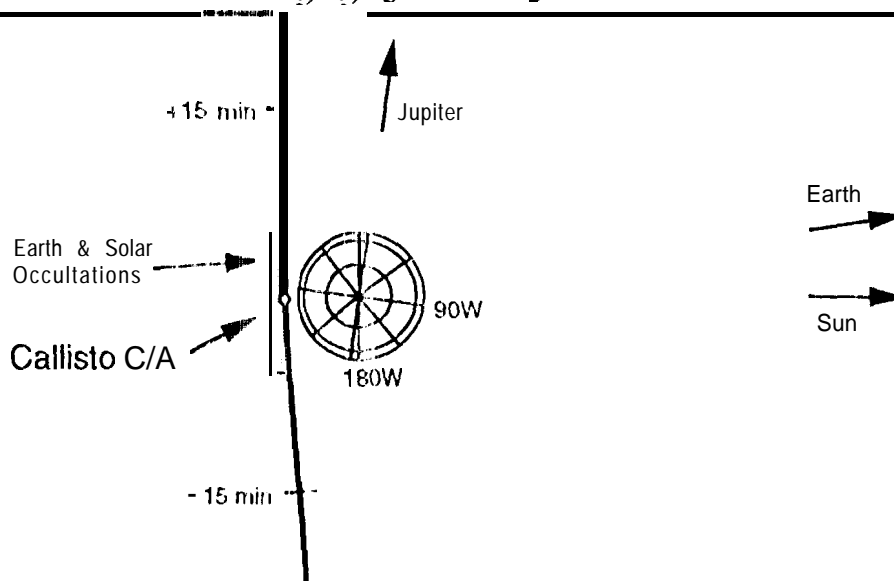
- Callisto Valhalla multi-ringed structure
- Ganymede non-targeted encounter
- Metis, Adrastea, Amalthea, Thebe

Jovian Atmosphere

- Great Red Spot
- Equatorial plume head
- Jupiter northern and southern aurora, 10 footprint
- High solar phase angle

Callisto-Orbit 9

Callisto Flyby Geometry

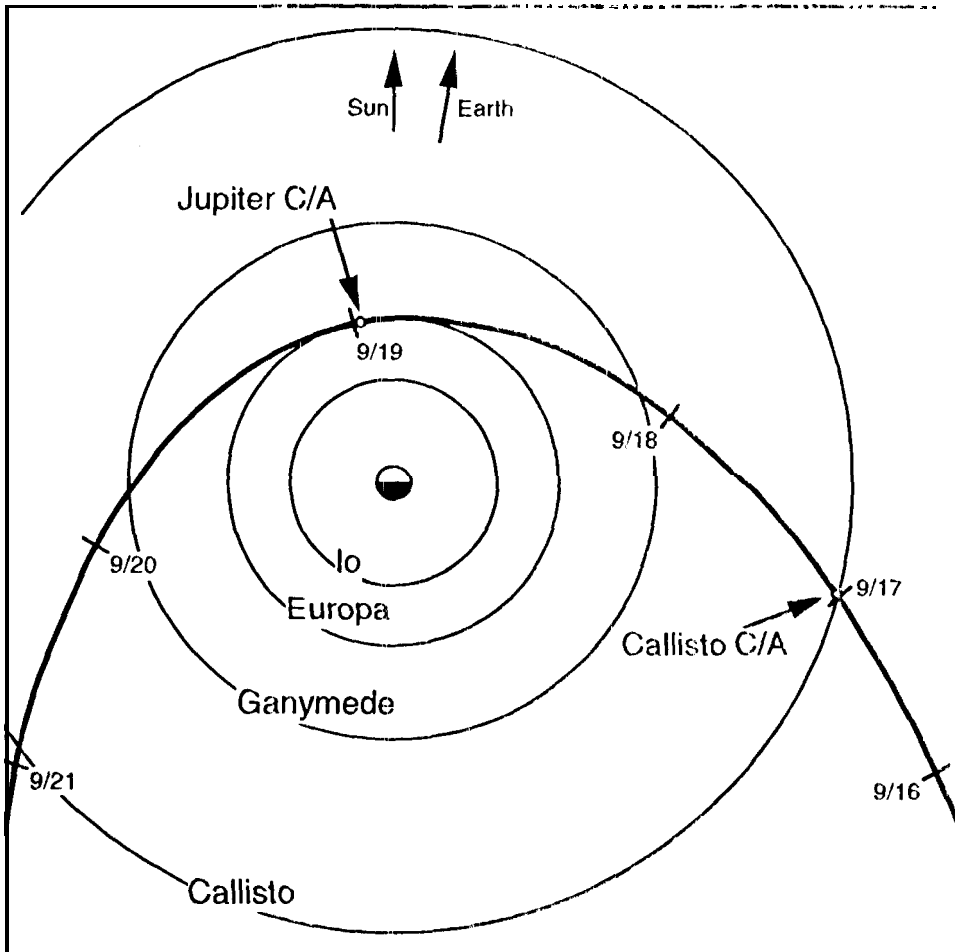


Time Ordered Listing

EVENT	TIME (PDT-SCET)		EVENT (continued)	TIME (PDT-SCET)	
Start Encounter	22 June 1997	09:00	Last monitoring observation (NIMS)		13:27
OTM-29		23:18	Last plume head observation (NIMS)		14:12
Science Turn (Callisto encounter)	24	23:18	Start Playback	29	09:00
Callisto dark map (PPR)	25	04:42	OTM 30	10 July	11:00
Callisto C/A recording (F&P)		06:26	Science Turn (Instrument calibration)	14	00:27
Start Earth occultation by Callisto		06:39	Turn to return to Earth point		05:41
Start Solar occultation by Callisto		06:40	Dusk magnetotail obs. @ 130 R _J (F&P)	23	07:19
Callisto C/A (2820 km)		06:47	Start Solar occultation by Jupiter	29	04:54
End Earth occultation by Callisto		06:56	End Solar occultation by Jupiter	30	11:40
End Solar occultation by Callisto		06:58	Start Earth occultation by Jupiter	01 August	03:26
Callisto Skuld crater obs. (NIMS/UVS)		07:26	End Earth occultation by Jupiter	02	04:42
Callisto Valhalla regional obs. (SSI)		08:11	First apojove magnetotail obs. (F&P)	07	04:06
Turn to return to Earth point		12:04	Second apojove magnetotail obs. (F&P)		06:36
First Great Red Spot observation (SSI)		18:26	OTM-31	08	10:45
First plume head observation (SSI)		22:57	Turn for attitude maintenance	09	09:00
First Jupiter auroral observation (UVS)		23:27	Dawn magnetotail obs. @ 130 R _J (F&P)	23	07:07
Thebe imaging (SSI)		23:56	Science Turn (High phase Jupiter)	02 September	19:45
Adrastea imaging (SSI)	26	06:11	Jupiter high solar phase obs. (SSI)		22:56
Ganymede C/A (82600 km)		10:19	Turn to return to Earth point		23:31
Ganymede Perrine / Galileo Regio (SSI)		10:46	First Callisto-10 approach OPNAV	09	22:13
Ganymede polarimetry (PPR)		11:38	Science Turn (High phase Jupiter)	10	04:25
Ganymede global mosaic (NIMS)		14:53	Jupiter high solar phase obs. (SSI)		07:26
Amalthea imaging (SSI)		16:35	Turn to return to Earth point		08:01
Europa C/A (1200000 km)	27	03:09	Last Callisto-10 approach OPNAV	12	13:25
First 10 monitoring observation (NIMS)		03:33	End Playback	13	17:00
Metis imaging (SSI)		04:25			
Jupiter C/A (770000 km)		04:52			
10 C/A (607000 km)		19:31			
Last Jupiter auroral observation (UVS)	28	07:01			
Last Great Red Spot observation (NIMS)		0859			

Callisto Orbit 10

Encounter Trajectory



Quick Facts

Callisto Encounter

17 September 1997
00:21 UTC

Altitude: 524 km

237 times closer than VGR1
406 times closer than VGR2

Speed: 8,2 km/s

Latitude: 5 deg N

Longitude: 79 deg W

Perijove

18 September 1997
23:13 UTC

Altitude: 8,2 R_J

Earth Range: 4.3 AU

OWLT: 36 min

Encounter Phase

14-20 September

Cruise Phase

20 Sept -02 Nov

Science Highlights

Magnetosphere

- Completion of second "mini-tour" of Jovian magnetosphere
- Jupiter magnetic equator crossing

Satellites

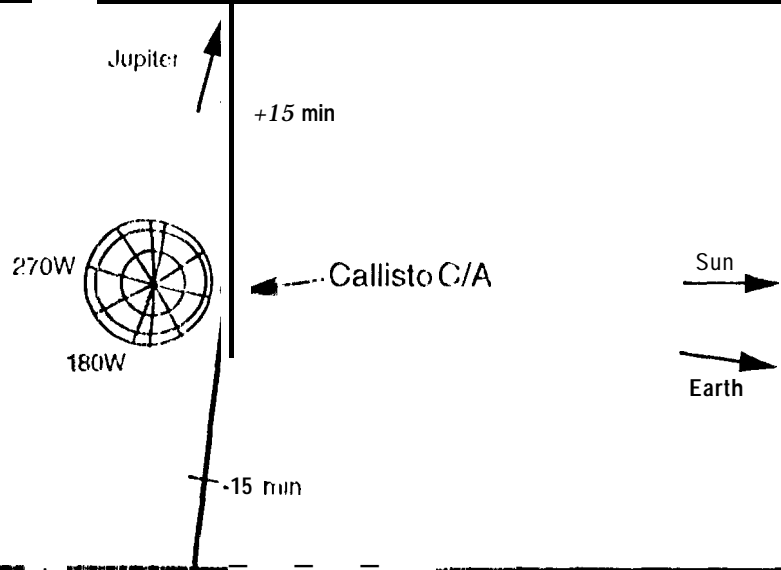
- Callisto global and bright limb observations
- Io aurora and Jupiter rings during solar occultation
- Europa volcanism survey
- Amalthea, Thebe, Adrastea, Metis, Himalia

Jovian Atmosphere

- North polar haze region
- Jupiter northern and southern aurora
- Jupiter aurora and lightning during solar occultation

Callisto - Orbit 10

Callisto Flyby Geometry — — — — — T



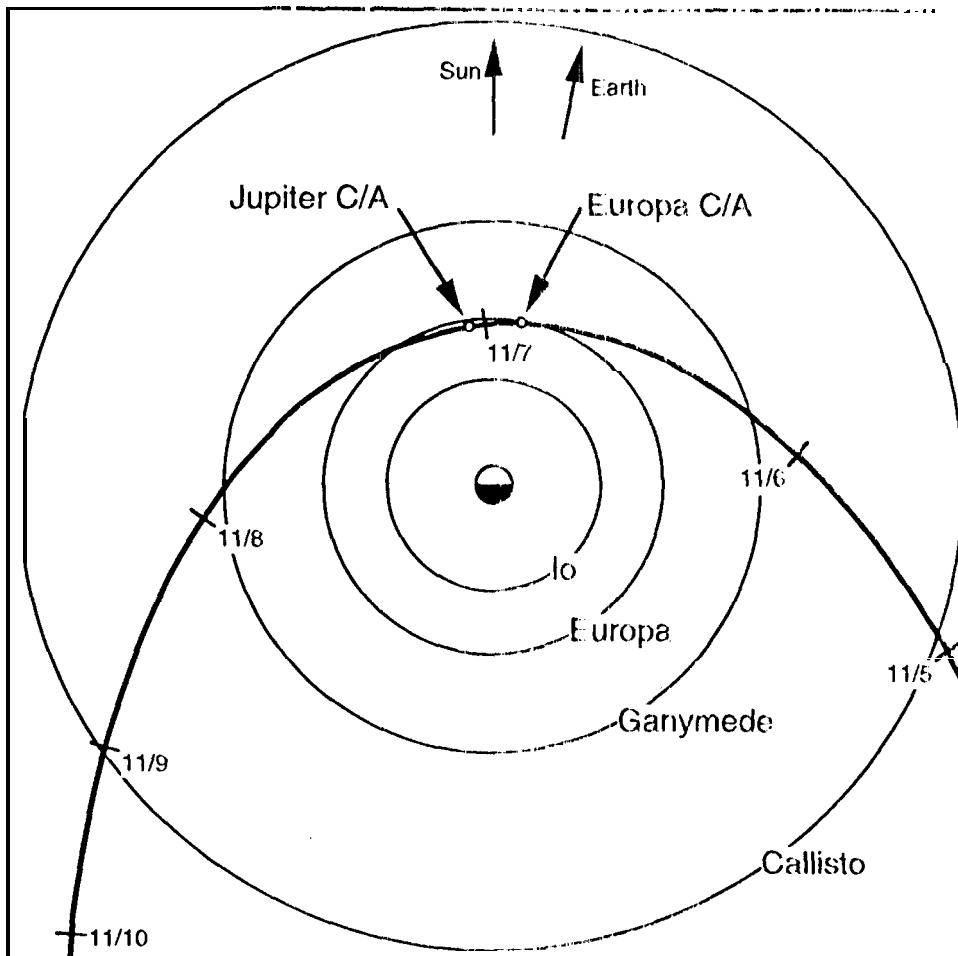
Time Ordered Listing

EVENT	TIME (PDT/PST-SCET)	EVENT (continued)	TIME (PDT/PST-SCET)
Start Encounter	13 September 1997 17:00	Last Jupiter aurora observation (NIMS)	21:14
OTM-32	19:00	Start Playback	20 07:30
Himalia observation (UVS)	16 04:59	Turn to return to Earth point	07:45
Callisto gravity field measurement (RS)	07:27	Last north polar haze region obs. (NIMS)	11:08
Callisto C/A recording (F&P)	16:52	OTM-33	14:30
Callisto Asgard transect (SSI)	16:56	Start Earth occultation by Jupiter	29 02:51
Callisto C/A (2930 km)	17:21	End Earth occultation by Jupiter	30 03:19
Callisto bright limb obs. (NIMS/UVS)	17:23	Start Solar occultation by Jupiter	05 October 06:00
First Jupiter aurora observation (UVS)	17 07:12	Science Turn (Solar occultation)	07:43
First north polar haze region obs. (UVS)	09:01	Europa volcanism observation (SSI)	11:04
First 10 monitoring observation (NIMS)	14:34	Jupiter lightning/aurora obs. (SSI)	11:09
Amalthea observing (NIMS)	18 08:09	10 auroral/Jupiter rings obs. (SSI)	12:48
Ganymede C/A (1690000 km)	10:58	Turn to return to Earth point	18:50
Jupiter magnetic equator recording (F&P)	15:36	End Solar occultation by Jupiter	23:59
Jupiter C/A (656000 km)	16:13	OTM-34	18 09:00
Adrastea/Metis observation (NIMS)	17:15	End 2nd magnetosphere "mini-tour" (F&P)	25 15:00
10 C/A (319000 km)	21:43	First Europa-11 approach OPNAV	28 18:15*
Europa C/A (621000 km)	22:23	Start Europa-11 real-time survey (F&P)	01 November 14:00
Thebe imaging (SSI)	19 00:16	Last Europa-11 approach OPNAV	02 03:45
Science Turn (High phase Jupiter)	00:47	End Playback	08:00
Last 10 monitoring observation (NIMS)	17:41		

*denotes transition from PDT to PST,

Europa - Orbit 11

Encounter Trajectory



Quick Facts

Europa Encounter

06 November 1997

21:46 UTC

Altitude: 1125 km

651 times closer than VGR1

181 times closer than VGR2

Speed: 5.5 km/s

Latitude: 66 deg N

Longitude: 144 deg W

Perijove

07 November 1997

00:57 UTC

Altitude: 8.1 R_J

Earth Range: 5.0 AU

OWLT: 41 min

Encounter Phase

02-09 November

Cruise Phase

09 Nov -07 Dec

Science Highlights

Magnetosphere

- Europa Alfvén wing crossing
- Last real-time survey of Jovian magnetosphere

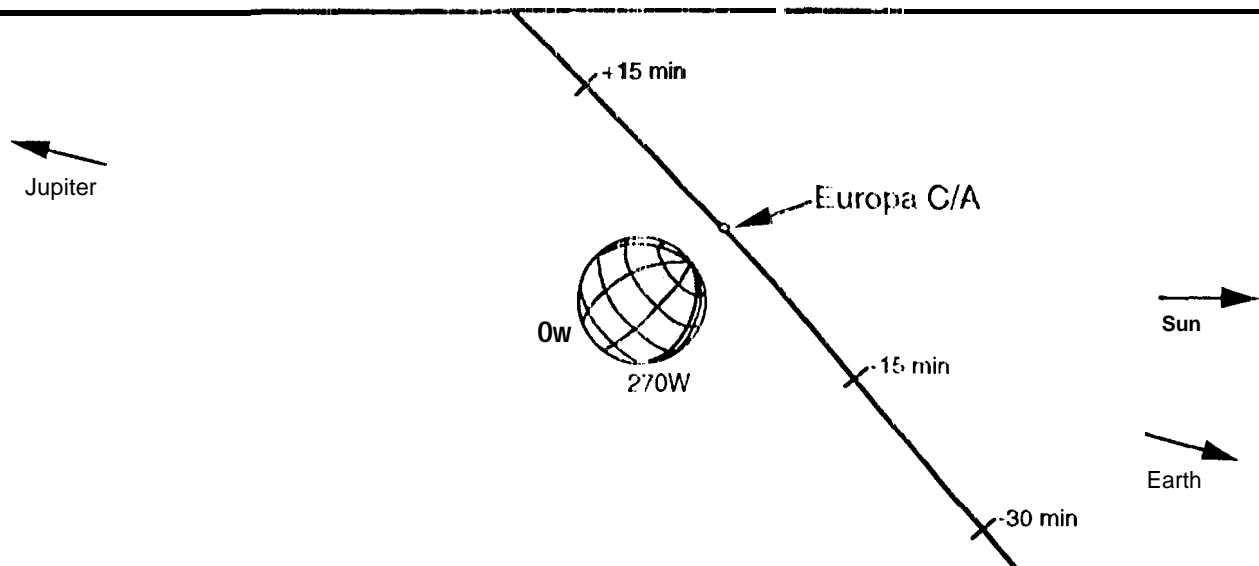
Satellites

- First close range Europa observations with Ultraviolet Spectrometer
- Mass properties of Europa

Jovian Atmosphere

- Global equatorial hydrogen map
- Jupiter aurora

Europa Flyby Geometry



Time Ordered Listing

EVENT	TIME (PST-SCET)
Start Encounter	02 November 1997 08:00
OTM-35	03 13:46
Callisto C/A (682000 km)	04 23:35
Europa C/A (2690 km)	06 13:46
Jupiter C/A (652000 km)	16:57
Ganymede C/A (1560000 km)	07 02:10
10 CIA (780000 km)	15:23
Start Playback	09 08:00
End Playback	07 December 1997 08:00

End of Galileo Prime Mission 07 December 1997 08:00

* Science details of the Europa -11 encounter and cruise have not been determined at this time.